NCWA
Northern California Water Association

SACRAMENTO VALLEY WATER QUALITY COALITION
SVWQC

December 20, 2018

Dr. Karl Longley, Chairman
Central Valley Regional Water Quality Control Board
11020 Sun Center Drive, #200
Rancho Cordova, California 95670

RE: Comments on Order R5-2014-0300-06 (Sacramento Valley WDR)

Dear Chairman Longley:

Since the adoption of the first Irrigated Lands Waste Discharge Requirements (WDRs) General Orders six (6) years ago a lot has been learned. More is understood about groundwater quality and potential impacts from agriculture on groundwater quality.

The adoption of the 2012-2014 General Orders was a catalyst for a significant investment by owners and operators of irrigated agriculture, their partners at Resource Conservation Districts, University of C Cooperative Extensions the University of California, USDA Natural Resources Conservation Service, commodity groups and agricultural organizations. Extensive work to advance knowledge of probable impacts from agricultural nitrogen applications on groundwater quality has been completed, including the technical work done through the CV-SALTS (Salt and Nitrate Basin Plan Amendment), which has provided a comprehensive characterization of groundwater quality conditions throughout the production zone.

In the Sacramento Valley, NCWA as the third party representing the Sacramento Valley Water Quality Coalition (Coalition), completed in 2016 the Groundwater Quality Assessment Report (GAR) which determined High Vulnerability Areas (HVAs) based on hydrogeologic susceptibility to estimate risk of degradation to groundwater and a detailed evaluation of groundwater quality data, as well as identifying Disadvantaged Communities (DACs) reliant on groundwater as a significant source of drinking water that lie within or are subject to potential impacts from HVAs. The Coalition has also been an active participant in the Management Practices Evaluation Program (MPEP), implemented a Comprehensive Groundwater Quality Management Plan (GQMP), and begun sampling wells as part of the Groundwater Quality Trend Monitoring Workplan approved by the Regional Water Board. All of these have increased awareness among the Coalition's Members about the importance of protecting groundwater quality.

Additionally, fifteen years of surface water quality monitoring results in the Sacramento Valley has shown, with limited exception, that owners and operators of irrigated agriculture are using practices protective of water quality. Even the Coalition's 2018 Surface Water Monitoring Plan, which included sampling for an expanded list of pesticides, as directed by the Pesticides Evaluation Protocol and List of Pesticides, saw only three (3) exceedances of water quality objectives out of 2253 samples analyzed. This includes monitoring for the six (6) pyrethroids identified in the Amendment to the Water Quality Control Plan for the Sacramento and San Joaquin River Basins for the Control of Pyrethroid Pesticide Discharges.

In 2014, the wealth of information available today about surface and groundwater quality wasn't available. Therefore it was appropriate that General Order R5-2014-0030 establish groundwater quality elements to collect this information.

The next generation of Irrigated Lands should reflect the progress made and be informed by not only the information collected by the Coalition, but the technical work done by CV-SALTS and other research work.

Therefore the Coalition requests the following revisions *to R5-2014-0030-06 Waste Discharge Requirements General Order for Growers within the Sacramento River Watershed that are Members of a Third-Party Group.*

> **New Economic Analysis** -The State Water Resources Control Board Order WQ-2018-0002 will increase costs for Third-Parties and its Members. An updated *Technical Memorandum Concerning the Economic Analysis of the Irrigated Lands Program* (Economic Report) should be prepared to reflect these new costs. (Section XV. California Water Code Sections 13142 and 13241, Attachment A to Order R5-2014-0030-06, Pages 61-63).
>
> **Change to Surface Water Quality Monitoring Cycle** - To offset increasing costs and to reflect consistently high quality surface water monitoring results we request a change to the Surface Water Quality Monitoring Frequency at Representative Sites to Assessment/Core/Core beginning in 2021. (Section III. A. 1. Attachment B to General Order No. R5-2014-0030-06, Page 5).
>
> **Greater Agricultural Commissioner Role** - Support Coalition initiative to restore an Agricultural Commissioner Memorandum of Agreement in the Sacramento Valley. The success of this initiative in Glenn County proves that outreach and education is a catalyst for change that is protective of water quality.

Focus of Management Practices Documentation - Management Practices Implementation Reports (MPIR) should only be required for high priority Surface Water Quality Plans (SQMP) related pesticides, toxicity, metals, and nutrients, where owners and operators can demonstrate they are using management practices to control any contribution from irrigated agricultural operations. (Section VII. G., Page 34 of WDR).

Change Date to Determine Outliers - The "July 1, 2019" date (Section IV. C. 8. c., Page 25 of WDR) is the one the State Water Board set for the Eastern San Joaquin General Order WDR. The Regional Board has the discretion to set a different date in R5-2014-0030-06. Given the work that needs to be done to finalize crop coefficients and the relative priority of basins in the Sacramento Valley, the Coalition requests "July 1, 2022" be established as the date for Coalition to propose an approach for defining a set of Members as outliers. Extending the deadlines for groundwater related requirements in the Sacramento Valley also would better match up with timelines in our region for other related processes like CV SALTS and Groundwater Sustainability Plans. With all Members of the Coalition required to do an INMP Summary Report beginning March 1 2021 (Section VII. D. 2., Page 33 of WDR) this would allow sufficient time to collect multi-year, crop specific information to establish more accurate and useful data to determine actual outliers and provide them information that is meaningful.

Change Date for Members to Complete MPIR - The "1 March 2020" date is the one the State Water Board established for the Eastern San Joaquin General Order WDR for Members in areas subject to a Surface Water Quality Management Plan (SQMP) or Groundwater Quality Management Plan (GQMP) to complete a Management Practices Implementation Report (MPIR). (Section VII. G., Page 34, R5-2014-0030-06). The Regional Board has the discretion to set a different date in R5-2014-0030-06. Given that Coalition Members in pesticide or toxicity SQMP are currently completing focused management practices surveys, it is proposed the date change to 1 March 2022 which will permit the Coalition to incorporate the report into the On-line Data Management Tool currently being developed for Members to input their information and, for GQMP, allow information from revisions to the Groundwater Quality Assessment Report (GAR) to inform the revised Comprehensive GQMP.

Eliminate Groundwater Quality Protection Formula, Values and Targets - The State Water Board made *"The development of the Groundwater Protection Formula, Values, and Targets shall be precedential for the third parties that proposed the methodology."* (WQ-2018-0002, Page 66). The Coalition was not one of those third parties. Further the State Water Board gave Regional Boards the discretion to apply *"this methodology **or a similar methodology,** designed to determine targets for nitrogen loading within high priority townships or other geographic areas,"* (Page 66). Given the State Water Board Order also states, *"The multi-year A/R ratio and the A-R difference are thus appropriate metrics for determining measurable progress toward ensuring agricultural discharges are not causing or contributing to exceedances of water quality standards in the groundwater."* (Page 65). If these requirements cannot be eliminated, the deadlines should be adjusted for the Sacramento Valley Region for reasons stated above in "Determining Outliers" section. **Eliminate reference to Groundwater Quality Protection Targets**. (Section VIII. E., Page 36, R5-2014-0030-06).

Change date for Annual Report of Management Practice Implementation and Nitrogen Application (Section VIII. D., Page 36, R5-2014-0030-06, and Attachment B MRP sections V.C. and V.D.). With all Members of the Coalition required to do an INMP Summary Report beginning March 1 2021 (Section VII. D. 2., Page 33 of WDR) changing the date from 30 November 2020 to 30 November 2022 would allow sufficient time to collect meaningful multi-year information on management practices and multi-year, crop specific nitrogen application information to demonstrate progress on addressing agricultural contributions from irrigated agriculture. **Eliminate use of the Department of Pesticide Regulations (DPR) Groundwater Protection Areas** as the sole determinate of High Vulnerability Areas (Section VIII. J. 2. b., Page 40 R5-2014-0030-06)

The Coalition appreciates the Regional Board's consideration of these requests. The justification for these requested revisions is provided in the attached memo. As always the Coalition is available to discuss these comments and requests.

Sincerely,

Bruce Houdesheldt
Director Water Quality
Northern California Water Association

Cc:	Denise Kadara Raji Brar	Robert Schneider Dr. Dan Marcum	Carmen Ramirez Mark Bradford
	Patrick Pulupa Rebecca Tabor	Sue McConnell	Susan Fregien

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SACRAMENTO VALLEY WATER QUALITY COALITION
SVWQC

TO: Dr. Karl Longley, Chair
Boardmembers, Central Valley Regional Water Quality Control Board

FROM: Bruce Houdesheldt
Director Water Quality
Northern California Water Association

DATE: December 20, 2018

RE: **Materials Supporting Requests for Modification of R5-2014-0030-06**

Northern California Water Association (NCWA), as the Third-Party representing the owners and operators of irrigated lands in the Sacramento River Watershed, has submitted comments on the Public Review Draft of Waste Discharge Requirements (WDR) General Order No. R5-2014-0030-06. The purpose of this memo is to provide documentation in support of the requested modifications.

At the outset NCWA and the Coalition wish to acknowledge and appreciate the Central Valley Regional Water Quality Control Board's (Regional Water Board) approach to regulating irrigated agriculture through the Coalition model versus requiring individual farming operations to be permitted and conduct surface and groundwater quality monitoring and reporting. The Sacramento Valley Water Quality Coalition (Coalition) is the largest of the Agricultural Water Quality Coalitions in the number of members (~8300), number of irrigated acres (~1,330,000) and footprint (~27,000 square miles) in California and perhaps the United States. With six National Wildlife Refuges, more than fifty state Wildlife Areas, and other privately managed wetlands that support the annual migration of waterfowl, geese and water birds in the Pacific Flyway and habitat for 50% of the threatened and endangered species in California, including winter-run and spring-run salmon, steelhead and many other fish species, the Sacramento River Watershed is uniquely different from the other landscapes in which irrigated agriculture operates in the Central Valley.

Additionally, the Sacramento River Watershed has significant irrigated lands operations in the upper watersheds. The Regional Water Board's recognition that these operations are distinctively different from the farming operations on the valley floor both in size of operation, seasonality of growing season, and value of crops grown has been an important aspect of crafting a regulatory program that meets the requirements of protecting water quality without overly burdening Coalition Members in these areas with monitoring and reporting costs.

Nonetheless, Court Rulings, direction from State Water Resources Control Board (State Water Board) and a sevenfold increase in the State Water Quality fee (12 cents to current fee of 95 cents) have created an increased burden on all Sacramento Valley Coalition members. All at a time when farm economies are under financial pressure. It is for this reason NCWA on behalf of the Coalition submits these recommended revisions to General Order No. R5-2014-0030-06 to strike a balance between protecting water quality and costs.

New Economic Analysis

The Coalition's first recommendation is to prepare a new *Technical Memorandum Concerning the Economic Analysis of the Irrigated Lands Program (Economic Report),* Section XV. California Water Code Sections 13142 and 13241, Attachment A to Order R5-2014-0030-06, Pages 61-63). The current one is nearly a decade old.

The State Water Resources Control Board's February 7, 2018 revisions to the Eastern San Joaquin Waste Discharge Requirements (WDR) - State Water Resources Control Board Order WQ-2018-0002 - expanded and refined the focus of actions growers and Coalitions statewide will need to take. Actions like requiring all growers to complete Irrigation and Nitrogen Management Summary Reports, regardless of whether there is a risk to safe drinking water, new reporting requirements of Management Practices and storing information for longer will each require a significant investment on the part of growers at the time when farm economics are challenged by increasing costs of regulatory fees, tariffs, sustainable groundwater management requirements and possible reallocation of nearly 1 million acre-feet of water away from the Sacramento Valley.

Additionally the Economic Analysis should capture other costs (watermaster fees, cost to comply with the Sustainable Groundwater Management Act, crop production costs, including power costs related to irrigation wells and water supply costs, etc.) that must be borne by an irrigated agricultural operation.

The State Water Board recognized the increased burden their decision placed on owners and operators of irrigated agriculture citing Water Code section 13267 which specifically directs that "[t]he burden, including costs of [monitoring] reports shall bear a reasonable relationship to the need for the report and the benefits to be obtained from the reports."

It is requested the Regional Board thoroughly review the Sacramento Valley WDR to ensure unnecessary and duplicative elements are eliminated. For instance, the Groundwater Quality Assessment Report GAR) was important when less was known about the groundwater quality. Now with additional work done by Dr. Thomas Harter, the technical work done by CV-SALTS in 2016 and several USGS and Lawrence Livermore groundwater quality investigations, the GAR and Comprehensive Groundwater Management Plans are less important.

Surface Water Quality Monitoring Cycle

To offset increased costs and reflect surface water quality results the Coalition requests the Regional Board to change the Surface Water Quality Monitoring Frequency at Representative Sites to Assessment/Core/Core beginning in 2021. (Section III. A. 1. Attachment B to General Order No. R5-2014-0030-06, Page 5).

As documented by nearly 15 years of surface water quality monitoring and analysis and the Coalition's Annual Monitoring Report, over 98.5% of all pesticide analyses performed to date for the Coalition have been below detection. Since 2005, in the Sacramento Valley, only 0.03% of the 42,258 pesticide analyses have exceeded water quality objectives. Similarly, only 2.7% of 2331 toxicity tests have had an effect on aquatic organisms that are indicative of a healthy aquatic ecosystem. As a result, the Sacramento Valley has fewer pesticide and toxicity management plans than other regions of the Central Valley.

Since 2008, the Coalition has funded actions that have resulted in completion of 25 Management Plans for pesticides and toxicity. Today, there are only 5 Management Plans in the Sacramento Valley. As evidenced by over a decade of surface water quality monitoring results, the management practices used by owners and operators of vineyards, orchards, row crops, and irrigated pasture have successfully protected water quality and beneficial uses, for both aquatic life and drinking water.

Based on this substantial information it is requested that the surface water quality monitoring cycle return to one year of Assessment Monitoring, followed by two years of Core Monitoring beginning in 2021.

Explore Expanded Agricultural Commissioner Role

The success of the first Memorandum of Understanding (MOU) signed by the Department of Pesticide Regulation (DPR), Agricultural Commissioners of Butte County and Glenn County (Agricultural Commissioners), Central Valley Water Board, and State Water Board is still paying dividends today. The MOU demonstrates that outreach and education is a more effective catalyst for protecting water quality than monitoring and reporting the results.

The Coalition has begun discussions with interested County Agricultural Commissioners in parts of the Sacramento Valley about reviving the MOU. The Coalition would like Regional Board's support of this effort.

Implementation of management practices are a critical element of water quality protection. Reviving the Agricultural Commissioner MOU that existed from 2007-2010 which focused on education over water quality sampling, will provide assurance that irrigated agriculture is not causing or contributing to surface water quality impairment.

Focus of Management Practices Documentation

Management Practices Implementation Reports (MPIR) should only be required for Surface Water Quality Plans (SQMP) related pesticides, toxicity, metals, and nutrients, where owners and operators can demonstrate they are using management practices to control any contribution from irrigated agricultural operations. (Section VII. G., Page 34 of WDR).

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The Coalition is part of the Northern Coalitions MPEP group which submitted its update Workplan on December 1, 2018, which has a crop prioritization list and a literature search and evaluation of the relevance of published information on crop coefficients. The State Water Board recognized it would take time to develop the relevant coefficients for calculating nitrogen removed by crop and directed,

> *"the Third Party to publish nitrogen removed coefficients for crops that cover 95% of acreage within the General WDRs' boundaries in time for use with the INMP Summary Reports due 1 March 2021 and 99% of the acreage in time for use with those due 1 March 2023"*

A revised date of July 1, 2022 would allow this work to be completed and the Regional Water Board to review and approve the coefficients in consultation with State Water Board staff, following an opportunity for public review and comment.

Change Date for Members to Complete MPIR

The "1 March 2020" date is the one the State Water Board established for the Eastern San Joaquin General Order WDR for Members in areas subject to a Surface Water Quality Management Plan (SQMP) or Groundwater Quality Management Plan (GQMP) to complete a Management Practices Implementation Report (MPIR). (Section VII. G., Page 34, R5-2014-0030-06).

The Regional Board has the discretion (Page 29, Order WQ 2018-0002) to set a different date in R5-2014-0030-06.

> *"The requirement for submission by all growers of management practice implementation information shall be precedential for irrigated lands regulatory programs statewide, however, the regional water boards shall continue to have discretion as to the form and frequency of such submissions."*

Given that Coalition Members in pesticide or toxicity SQMP are currently completing focused management practices surveys, it is proposed the date change to 1 March 2022 which will permit the Coalition to incorporate this information into the On-line Data Management Tool currently being developed for Members to input their information and, for GQMP, allow information from revisions to the Groundwater Quality Assessment Report (GAR) to inform the revised Comprehensive GQMP.

Eliminate Groundwater Quality Protection Formula, Values and Targets

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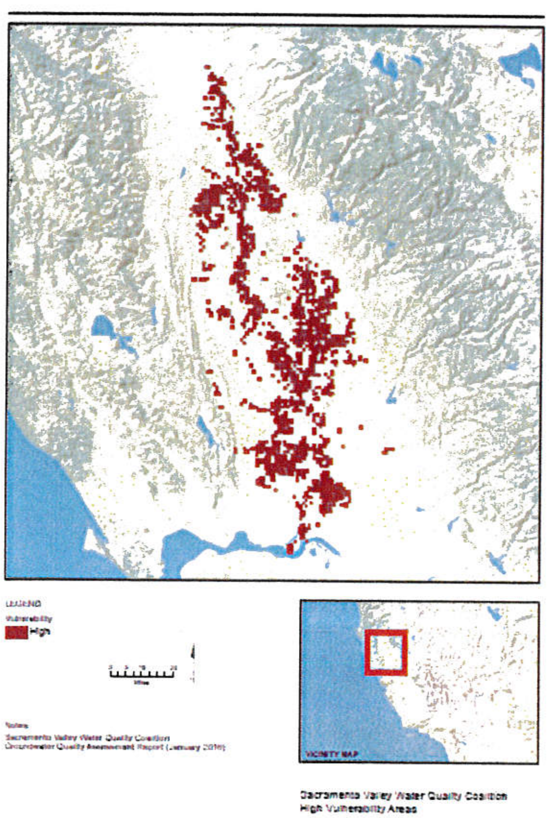
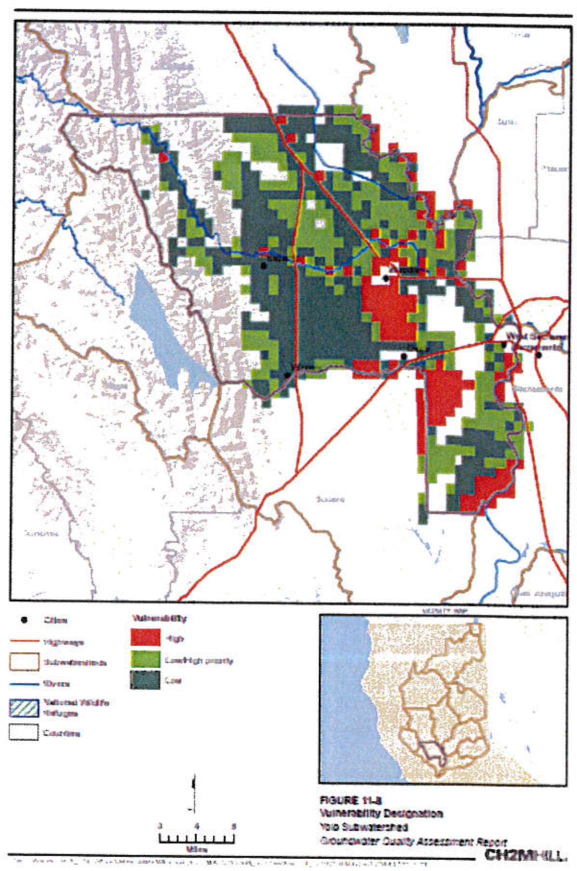
The Coalition was not one of those third parties. Further the State Water Board gave Regional Boards the discretion to apply *"this methodology **or a similar methodology**, designed to determine targets for nitrogen loading within high priority townships or other geographic areas,"* (Page 66).

Given the checkerboard pattern of sections of High Vulnerability Areas (HVA) – see map below - there is limited utility of establishing Groundwater Protection Formula Value and Targets at township level.





The Sacramento Valley Groundwater Quality Assessment Report which concludes

> *In general, nitrate concentrations are very low in the groundwater of the Sacramento River Watershed, with the exception of a few localized impacted areas. Generally, these areas showing elevated nitrate levels also tend to have associated land uses other than irrigated agriculture that might influence nitrate levels in groundwater. Looking specifically at the valley floor area, of the 2,645 recent well samples reviewed, the average nitrate (as NO3) concentration is 11 mg/L, which is well below half the MCL (22.5 mg/L). In addition, five percent of all recent well samples had concentrations above the MCL of 45 mg/L. These data indicate that even on the valley floor, where 80 percent of the agricultural production in this watershed occurs, nitrate concentrations are low, and irrigated agriculture does not appear to pose a significant threat to groundwater quality.*

This equates to 231,458 acres (21% of the Valley Floor portion of the Coalition) in sections that overlie groundwater with nitrate concentrations between half the MCL and the MCL, above the MCL or do not include sufficient wells with nitrate results to estimate the generalized groundwater nitrate concentration.

The CV-SALTS High Resolution Monitoring and Mapping Work done in 2016 show a more highly refined picture of groundwater quality conditions. As the Section 3 (below) shows the trends overtime do not show a trend of degradation from nitrate in the Sacramento Valley.

Table 3-8. Trends in Ambient Nitrate Concentrations in Central Valley IAZs (Value count refers to the number of values the calculated median concentration is based on; colors are used to show relative differences in concentration from low [green] to high [red])

Shallow Nitrate Median Concentration (mg/L NO3-N) Through Time														
		1910-1964		1965-1970		1971-1979		1980-1989		1990-2002		2003-2012		Trend
	IAZ	Median	Value Count	Median	Value Count	Median	Value Count	Median	Value Count	Median	Value Count	Median	Value Count	
Nothern Central Valley	1					0.1	1					0.1	41	No apparent trend
	2	1.1	29	1.3	13	2.2	86	3.0	30	2.4	12	0.6	75	No apparent trend
	3	2.3	6	1.2	6	1.3	34	1.3	7	0.7	22	0.9	62	No apparent trend
	4			0.2	7	0.2	11	0.0	2	0.1	7	2.8	17	No apparent trend
	5	1.1	8	1.2	4	1.4	48	2.5	7	0.8	13	0.4	80	No apparent trend
	6			1.8	8	3.6	14	3.4	17	0.2	3	0.6	106	Slightly decreasing
	7	0.8	8	1.2	2	1.5	5	1.8	4	1.7	9	0.7	76	No apparent trend
Middle Central Valley	8	1.1	24	2.5	9	1.9	13	2.4	12	1.5	11	1.2	345	No apparent trend
	9	4.9	8	2.9	4	0.1	7	0.1	7	0.1	10	0.4	218	No apparent trend
	10	3.4	4					2.7	7	2.2	4	2.7	65	No apparent trend
	11			3.2	3	7.5	4	12.6	8	8.1	4	4.9	254	Increasing to decreasing?
	12							0.1	1	3.4	11	10.4	220	Increasing
	13			7.9	3			4.4	8	5.4	21	6.1	195	Slightly increasing
	22	3.4	1					[illegible]	18	17.5	17	7.4	89	Slightly decreasing
Southern Central Valley	14	3.4	1	2.5	1			21.0	75			0.4	14	No apparent trend
	15							1.2	67	11.3	26	3.0	192	Increasing to decreasing?
	16	5.7	1					8.2	6	7.9	19	11.1	36	Slightly increasing
	17	6.0	2			8.1	1	8.0	10	10.1	33	8.5	100	Slightly increasing
	18							14.5	3	15.0	21	10.7	362	No apparent trend
	19	3.6	3					4.9	40			3.3	42	No apparent trend
	20	0.6	6					1.6	1			3.4	14	Slightly increasing
	21	0.7	8			8.6	1	8.6	23	0.3	5	0.2	45	Increasing to decreasing?

Section 3 • Salt and Nitrate Conditions in the Central Valley Region

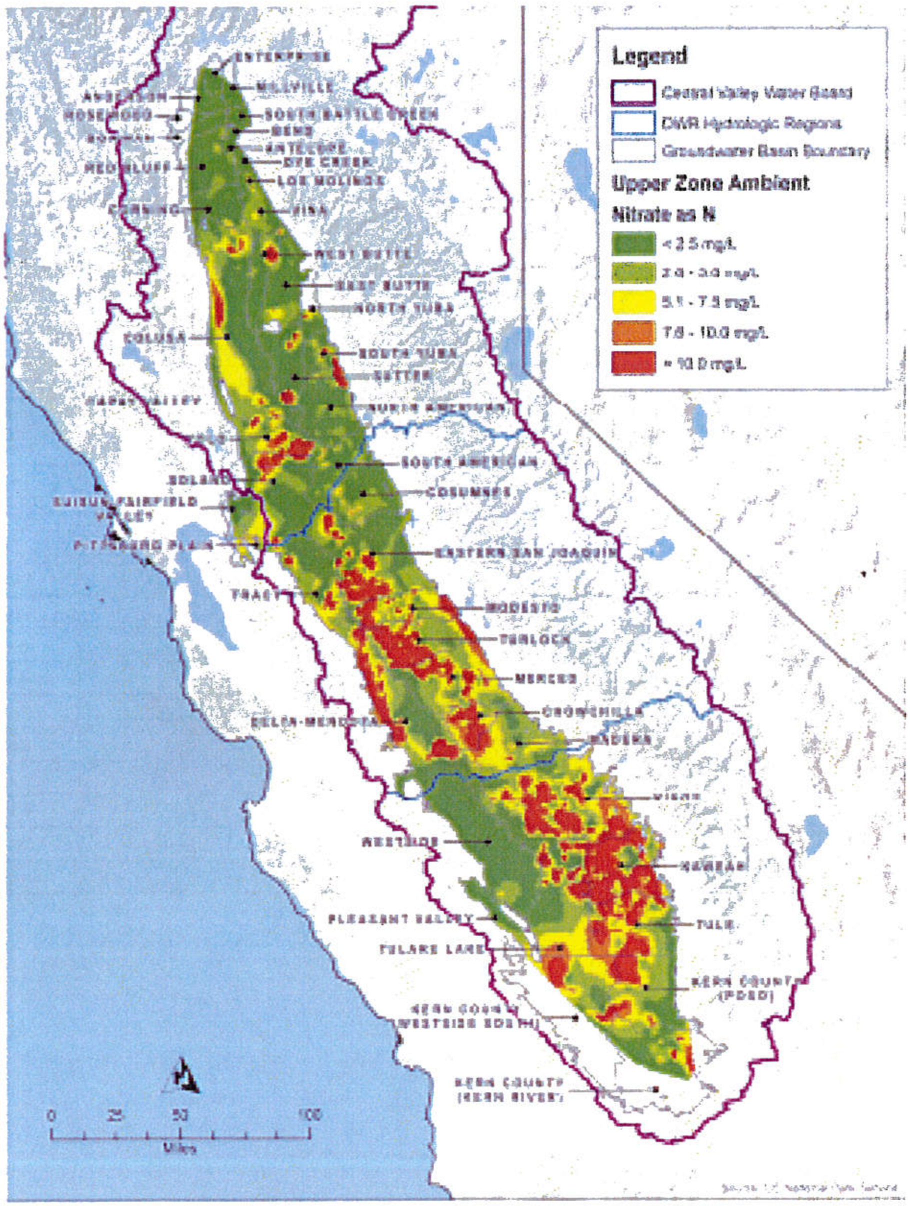


Figure 3-23. Ambient Conditions for Nitrate (mg/L as N) in the Upper Zone of Groundwater Basins/Subbasins in the Central Valley Floor.

The State Water Board Order also states, *"The multi-year A/R ratio and the A-R difference are thus appropriate metrics for* ***determining measurable progress toward ensuring agricultural discharges are not causing or contributing to exceedances*** *of water quality standards in the groundwater."* (Page 65)

For the Sacramento Valley the multi-year A/R ratio and the A-R difference should be the metric not the Groundwater Quality Formula, Value and Targets.

USGS
science for a changing world

CALIFORNIA
Water Boards

U.S. Geological Survey and the California State Water Resources Control Board

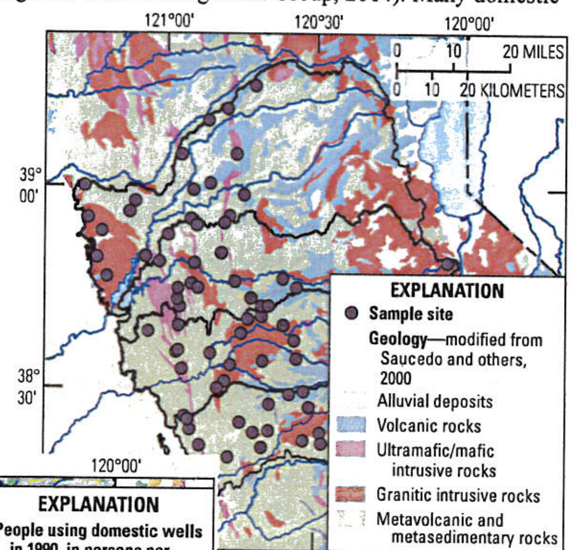
Groundwater Quality in the Mokelumne, Cosumnes, and American River Watersheds, Sierra Nevada, California

Groundwater provides more than 40 percent of California's drinking water. To protect this vital resource, the State of California created the Groundwater Ambient Monitoring and Assessment (GAMA) Program. The GAMA Program's Priority Basin Project assesses the quality of groundwater resources used for drinking-water supply and increases public access to groundwater-quality information. In the Mokelumne, Cosumnes, and American River Watersheds of the Sierra Nevada, many rural households rely on private wells for their drinking-water supplies.

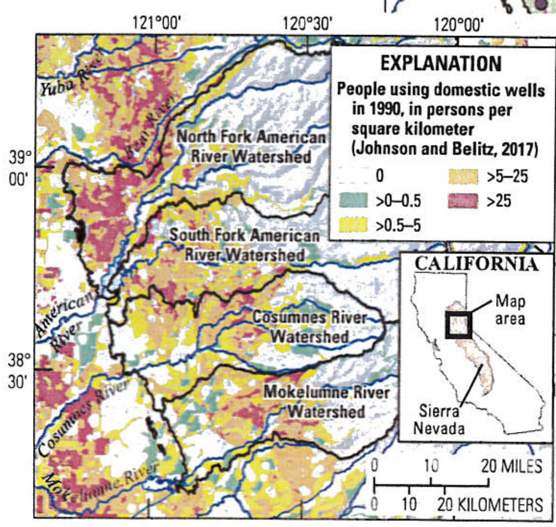
The Mokelumne, Cosumnes, and American River Watersheds

The Mokelumne, Cosumnes, and American River Watersheds (MCAW) study unit covers approximately 9,000 square kilometers on the western slope of the Sierra Nevada. Groundwater composes about 10 percent of overall water use in the region, but is the sole supply for many individual homes outside the public water-supply infrastructure (Cosumnes, American, Bear, Yuba Integrated Regional Water Management Group, 2014). Many domestic wells in the MCAW study unit were deepened during the recent drought (California Department of Water Resources, 2014), highlighting the vulnerability of groundwater supplies and prompting increased interest in studies of Sierra Nevada groundwater systems.

Well water in the MCAW study unit mostly comes from fractured-rock aquifers. The quality of groundwater in these aquifers primarily depends on the type of rock, the age of the groundwater, and the type of human activities at the land surface. Previous groundwater studies in this area found elevated concentrations of nitrate, microbial indicators, and some trace elements in some wells (California State Water Resources Control Board, 2005; Fram and Belitz, 2014).

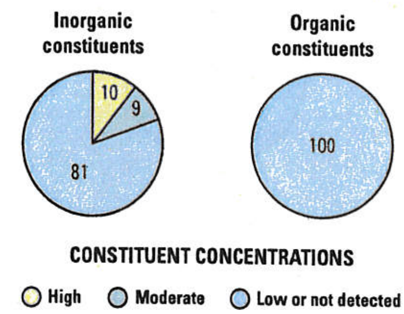


Base modified from U.S. Geological Survey and other Federal and State digital data, various scales; Albers Equal-Area Conic projection, standard parallels are 29°30' N and 45°30' N; North American Datum of 1983



This study was designed to provide a statistically representative assessment of the quality of groundwater resources used for domestic drinking water in the MCAW study unit. A total of 67 domestic wells and 1 domestic spring were sampled between August 2016 and January 2017 (Shelton and others, 2018). The wells in the study unit typically were 30 to 150 meters deep, and water levels typically were 2 to 42 meters below land surface.

Overview of Water Quality



Values indicate percentages of the area of the groundwater resources used for domestic drinking water with concentrations in the three specified categories.

The GAMA Priority Basin Project evaluates the quality of untreated groundwater. For context, concentrations measured in groundwater are compared to a constituent benchmark established for drinking-water quality, such as maximum contaminant levels (MCL). A concentration above the benchmark is defined as high. Benchmarks and definitions of moderate and low concentrations are discussed on page 3.

Many inorganic constituents are present naturally in groundwater, and their concentrations can be affected by natural processes and by human activities. In the MCAW study unit, one or more inorganic constituents were present at high concentrations in about 10 percent of the groundwater resources used for domestic drinking water.

Organic constituents are found in products used in the home, business, industry, and agriculture and can enter the environment through normal usage, spills, or improper disposal. Organic constituents were not present at high concentrations in the groundwater resources used for domestic drinking water in the MCAW study unit.

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U.S. Geological Survey

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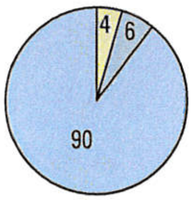
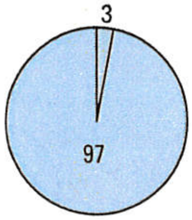
INORGANIC CONSTITUENTS

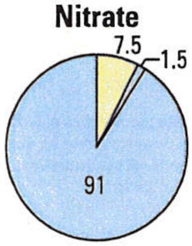
Trace elements



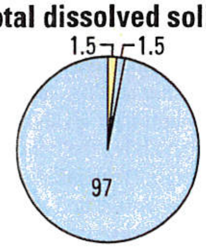
Uranium and radioactive constituents



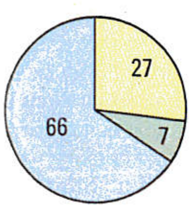
Nitrate



Total dissolved solids



Manganese or iron



Inorganic Constituents with Human-Health Benchmarks

Historical mining activity in the MCAW study unit and adjacent Yuba and Bear River watersheds has resulted in elevated concentrations of mercury and arsenic in water, sediments, and fish in some waterways and reservoirs (Alpers, 2017). Trace elements also are naturally present in the minerals of rocks and sediments and in the groundwater that comes in contact with those materials. About 4 percent of the groundwater resources used for domestic drinking water in the MCAW study unit had high concentrations of one or more trace elements, and about 6 percent had moderate concentrations. Three trace elements were present at high concentrations (arsenic, boron, and molybdenum), and three were present at moderate concentrations (arsenic, fluoride, and vanadium). Mercury was detected at low concentrations in about 1 percent of the groundwater resources.

As with trace elements, uranium and other radioactive constituents are naturally present in some minerals of rocks and sediments and in the groundwater that comes into contact with those materials. Radioactive constituents were not present at high levels in the groundwater resources used for domestic drinking water. Gross alpha-particle activity was present at moderate levels in about 3 percent of the groundwater resources.

Nitrate is naturally present at low concentrations in groundwater, but moderate and high concentrations generally indicate contamination from human activities. Common sources of nutrients include fertilizer applied to crops and landscaping, seepage from septic systems, and human and animal waste. About 8 percent of the groundwater resources used for domestic drinking water had high concentrations of nitrate, and less than 2 percent had moderate concentrations.

Inorganic Constituents with Non-Health Benchmarks

(Not included in water-quality overview charts shown on the front page)

Some constituents affect the aesthetic properties of water, such as taste, color, and odor, or can create nuisance problems, such as staining and scaling. The benchmarks used for these constituents were non-regulatory secondary maximum contaminant level benchmarks.

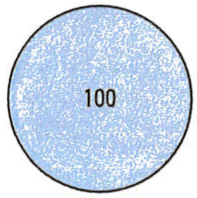
Total dissolved solids (TDS) concentration is a measure of the salinity of the groundwater, and all water naturally contains TDS as a result of the weathering and dissolution of minerals in rocks and sediments. The State of California has a recommended and an upper limit for TDS in drinking water (see box on page 3). Concentration of TDS were high (greater than the upper limit) in less than 2 percent of the groundwater resources used for domestic drinking water and moderate (between the recommended and upper limits) in less than 2 percent as well.

Anoxic conditions (low amounts of dissolved oxygen) can result in the release of natural manganese, iron, and other associated trace elements from minerals into groundwater. Anoxic conditions also can promote degradation of nitrate. About one-third of the wells sampled for the MCAW had anoxic conditions.

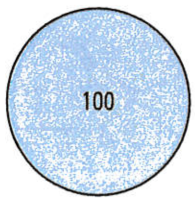
Manganese, iron, or both were present at high concentrations in about 27 percent of the groundwater resources used for domestic drinking water. In samples from the entire Sierra Nevada, groundwater from wells in metamorphic rocks more commonly had high or moderate concentrations of manganese or iron than groundwater from wells in granitic, volcanic, or sedimentary rocks (Fram and Belitz, 2014). More than half of the wells sampled for the MCAW were in metamorphic rocks.

ORGANIC CONSTITUENTS

VOCs



Pesticides



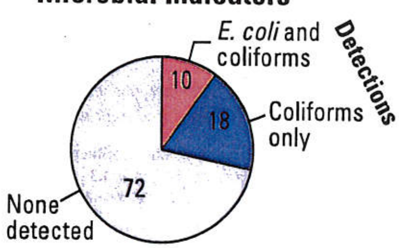
Organic Constituents with Human-Health Benchmarks

The Priority Basin Project used laboratory methods that can detect concentrations of volatile organic compounds (VOCs) and pesticides below human-health benchmarks. The VOCs and pesticides detected at very low concentrations can be used to help trace movement of water from the land surface into the aquifer system.

Volatile organic compounds are present in many household, commercial, and industrial products. No VOCs were detected at high or moderate concentrations in the groundwater resources used for domestic drinking water in the MCAW. Low concentrations of VOCs present in commonly used solvents or in gasoline were detected in about 21 percent of the groundwater resources.

Pesticides, including herbicides, insecticides, and fumigants, are applied to crops, gardens, lawns, around buildings, and along roads to help control unwanted vegetation, insects, fungi, and other pests. Pesticides were not detected at high or moderate concentrations in the groundwater resources of the MCAW used for domestic drinking water. Low concentrations of insecticides or herbicides were detected in about 18 percent of the groundwater resources.

Microbial Indicators



Microbial Indicators

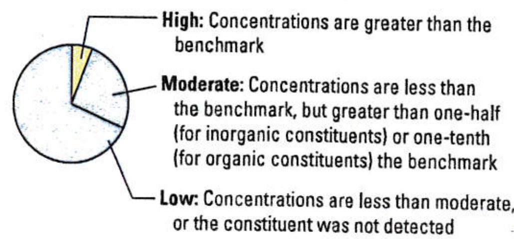
(Not included in water-quality overview charts shown on the front page)

Microbial indicators are used to evaluate the potential for fecal contamination of water sources. In the MCAW, total coliforms and *Escherichia coli* (*E. coli*) were detected in 10 percent of the wells sampled, and total coliforms alone were detected in another 18 percent of the wells sampled. Total coliforms are present naturally in soils and in digestive tracts of animals, whereas *E. coli* specifically indicate contamination with animal (or human) fecal waste (California State Water Resources Control Board, 2016). The pie diagram for microbial constituents uses different colors than the other pie diagrams because the benchmarks for microbial constituents specify repeat sampling to confirm detections, which was not done in this study.

Methods for Evaluating Groundwater Quality

This study uses comparison to benchmarks established for drinking water to provide context for evaluating the quality of groundwater. The quality of drinking water can differ from the quality of groundwater because of contact with household plumbing, exposure to the atmosphere, or water treatment. The U.S. Environmental Protection Agency (EPA) and California State Water Resources Control Board Division of Drinking Water (CA) regulatory benchmarks set for the protection of human health (maximum contaminant level, MCL, and treatment technique, TT) are used for comparison when available. Otherwise, non-regulatory benchmarks set for protection of aesthetic and technical properties, such as taste and odor (secondary maximum contaminant level, SMCL) and non-regulatory benchmarks set for the protection of human health (notification levels, NL, and lifetime health advisory levels, HAL) are used. Water quality in domestic wells is not regulated in California.

Pie diagrams are used to summarize groundwater quality results. The pie slices represent the percentages of the groundwater resources with high, moderate, and low concentrations of a constituent. Methods for calculating these percentages are discussed by Fram and Belitz (2014).



Benchmark type and value for selected constituents.

[Benchmarks are listed as EPA if the EPA and CA values are the same, and as CA if the CA value is lower or if no EPA value exists. **Abbreviations**: pCi/L, picocuries per liter; ppb, parts per billion (equivalent to micrograms per liter); ppm, parts per million (equivalent to milligrams per liter); >, greater than]

Constituent	Benchmark		Constituent	Benchmark	
	Type	Value		Type	Value
Arsenic	EPA MCL	10 ppb	Manganese	CA SMCL	50 ppb
Boron	CA NL	1,000 ppb	Iron	CA SMCL	300 ppb
Molybdenum	EPA HAL	40 ppb	Total dissolved solids, upper	CA SMCL	1,000 ppm
Fluoride	CA MCL	2 ppm	Total dissolved solids, recommended	CA SMCL	500 ppm
Vanadium	CA NL	50 ppb	*Escherichia coli* (*E. coli*)	EPA MCL	Repeat detection at a site
Gross alpha-particle activity	EPA MCL	15 pCi/L	Total coliform	EPA TT	>5 percent of samples with detections per month
Nitrate, as nitrogen	EPA MCL	10 ppm			

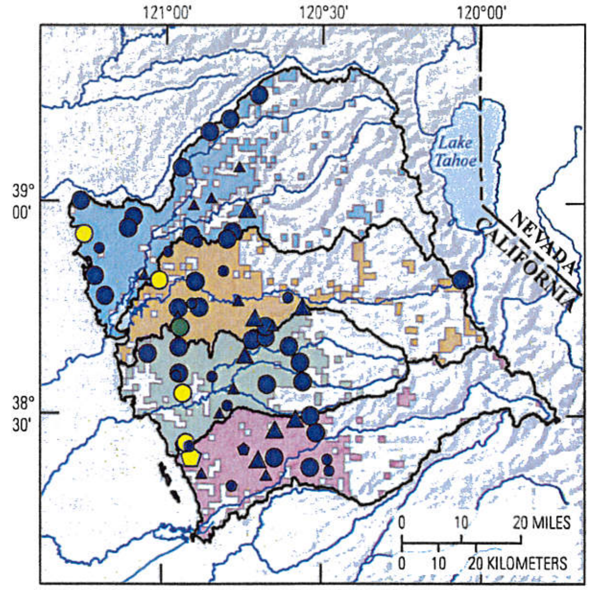
Factors that Affect Groundwater Quality

Of the constituents with maximum contaminant level (MCL) benchmarks, nitrate was the constituent present at high concentrations in the largest percentage of groundwater resources used for domestic drinking-water supply in the MCAW study unit (8 percent). Nitrate was present at concentrations above the EPA MCL of 10 ppm as nitrogen in all four watersheds in the MCAW study unit. High nitrate concentrations in groundwater generally require the three following conditions: anthropogenic sources of nitrate to groundwater, oxic geochemical conditions, and wells that tap "young" groundwater (Dubrovsky and others, 2010).

High nitrate concentrations were measured in samples from wells in the more populated western side of the MCAW study unit, where potential sources of nitrate are more common, including use of fertilizer on landscaping or for agriculture, seepage from septic and sewage systems, and recharge of surface water that does not meet water-quality standards ("impaired").

Tritium concentrations in groundwater can be used to estimate whether the groundwater was recharged primarily before 1950 ("old") or after 1950 ("young"). About three-quarters of MCAW study-unit well samples had tritium concentrations indicating "young" groundwater (Shelton and others, 2018; Jurgens and others, 2012). Young groundwater can be vulnerable to water-quality degradation from human activities and anthropogenic inputs at the land surface. The wells in the MCAW study unit with high and moderate concentrations of nitrate in the samples had young groundwater.

The percentage of groundwater resources used for domestic drinking water affected by contamination from anthropogenic sources of nitrate could be greater than the 8 percent estimated in this study. About one-third of the groundwater resources had anoxic geochemical conditions that could promote degradation of nitrate to reduced forms of nitrogen (ammonia, nitrite, and nitrogen gas). Only a few anoxic samples contained measureable concentrations of ammonia and nitrite (Shelton and others, 2018), however, indicating nitrate degradation was not widespread. All groundwater from MCAW study-unit wells with high and moderate concentrations of nitrate also had oxic geochemical conditions under which nitrate does not degrade rapidly.



Base modified from U.S. Geological Survey and other Federal and State digital data, various scales; Albers Equal-Area Conic projection, standard parallels are 29°30' N. and 45°30' N.; North American Datum of 1983

EXPLANATION

Watershed boundary

Study area

Cosumnes watershed — North Fork American watershed

Mokelumne watershed — South Fork American watershed

Nitrate concentration, in milligrams per liter of nitrogen	**Tritium concentration, in tritium units** Greater than 1.3 ("young")	Less than 1.3 ("old" or mixed)	No data
Greater than 10 (high)	○	—	⬠
5 to 10 (moderate)	●	—	—
Less than 5 (low)	● •	▲ ▴	—

Large symbols indicate oxic conditions; small symbols indicate anoxic conditions

By Miranda S. Fram and Jennifer L. Shelton

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For more information

Technical reports and hydrologic data collected for the GAMA Program's Priority Basin Project may be obtained from:

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Sacramento, CA 95819
Telephone number: (916) 278-3000
WEB: *http://ca.water.usgs.gov/gama*

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Division of Water Quality
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WEB:
http://www.waterboards.ca.gov/gama

U.S. Geological Survey and the California State Water Resources Control Board

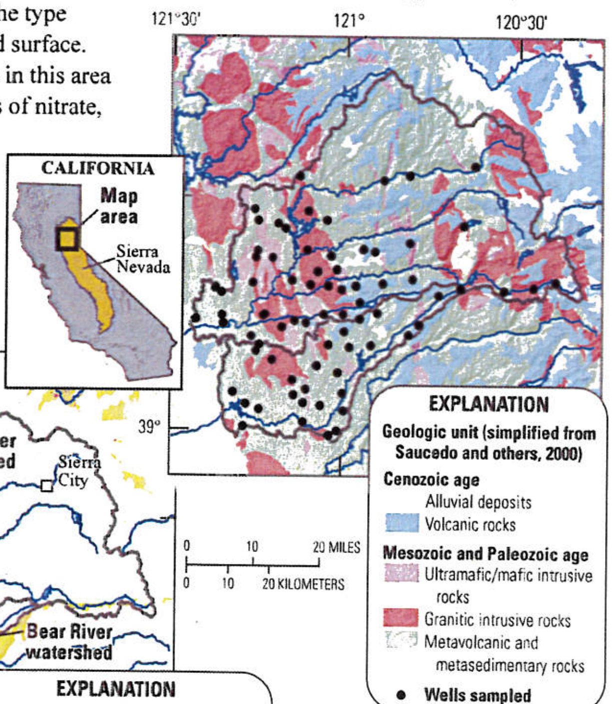
Groundwater Quality in the Yuba River and Bear River Watersheds, Sierra Nevada, California

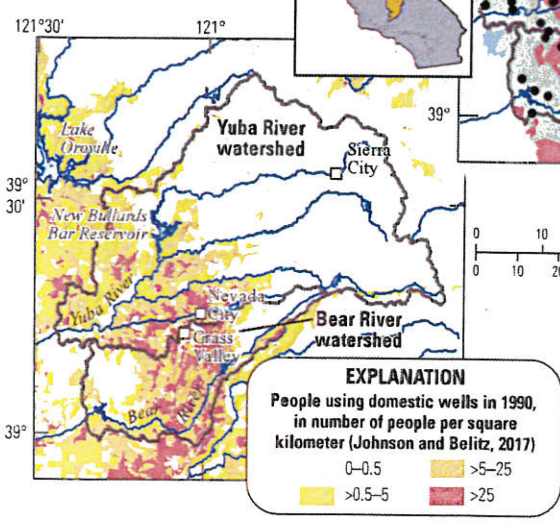
Groundwater provides more than 40 percent of California's drinking water. To protect this vital resource, the State of California created the Groundwater Ambient Monitoring and Assessment (GAMA) Program. The GAMA Program's Priority Basin Project assesses the quality of groundwater resources used for drinking water supply and increases public access to groundwater-quality information. In the Yuba River and Bear River Watersheds of the Sierra Nevada, many rural households rely on private wells for their drinking water supplies.

The Yuba-Bear Watersheds

The Yuba River and Bear River Watersheds study unit (Yuba-Bear Watersheds) covers approximately 4,400 square kilometers on the western slope of the Sierra Nevada. Groundwater composes about 10 percent of overall water use in the region, but is the sole supply for many individual homes beyond the limits of public water supply infrastructure (Cosumnes, American, Bear, Yuba Integrated Regional Water Management Group, 2014). Recent drought conditions highlighted the vulnerability of private wells to diminished groundwater supplies in the study area and many wells required deepening (California Department of Water Resources, 2014).

Well water in the Yuba-Bear Watersheds mostly comes from fractured-rock aquifers. The quality of groundwater in these aquifers primarily depends on the type of rock, the age of the groundwater, and the type of human activities at the land surface. Previous groundwater studies in this area found elevated concentrations of nitrate, microbial indicators, and some trace elements in some wells (California State Water Resources Control Board, 2010; Fram and Belitz, 2014).

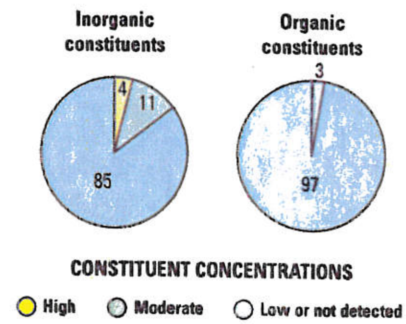




Base modified from U.S. Geological Survey and other Federal and State digital data, various scales; Albers Equal-Area Conic projection, standard parallels are 29° 30' and 45° 30'; North American Datum of 1983

This study was designed to provide a statistically representative assessment of the quality of groundwater resources used for domestic drinking water in the Yuba-Bear Watersheds. A total of 71 wells and 4 springs were sampled between October 2015 and May 2016 (Jasper and others, 2017). The wells in the study unit typically were 30–150 meters deep, and water levels typically were 7–25 meters below land surface.

Overview of Water Quality



Values indicate percentages of the area of the groundwater resources used for domestic drinking water with concentrations in the three specified categories.

GAMA's Priority Basin Project evaluates the quality of untreated groundwater. For context, concentrations measured in groundwater are compared to benchmarks established for drinking-water quality, such as maximum contaminant levels (MCL). A concentration above a benchmark is defined as high. Benchmarks and definitions of moderate and low concentrations are discussed on page 3.

Many inorganic constituents are natural in groundwater, and their concentrations can be affected by natural processes as well as by human activities. In the Yuba-Bear Watersheds, one or more inorganic constituents were present at high concentrations in about 4 percent of the groundwater resources used for domestic drinking water.

Organic constituents are found in products used in the home, business, industry, and agriculture, and can enter the environment through normal usage, spills, or improper disposal. Organic constituents were not present at high concentrations in the groundwater resources used for domestic drinking water in the Yuba-Bear Watersheds.

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INORGANIC CONSTITUENTS

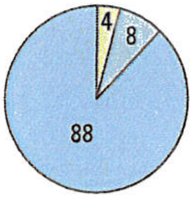
Inorganic Constituents with Human-Health Benchmarks

Historical gold-mining activity in the Yuba-Bear Watersheds has resulted in elevated concentrations of mercury and other trace elements in water and sediments in rivers and reservoirs. Trace elements also are naturally present in the minerals of rocks and sediments and in the groundwater that comes into contact with those materials. About 4 percent of the groundwater resources used for domestic drinking water had high concentrations of one or more trace elements and 8 percent had moderate concentrations. Four trace elements were present at high concentrations (arsenic, barium, molybdenum, and strontium), and three were present at moderate concentrations (arsenic, molybdenum, and vanadium). Mercury was detected at low concentrations in 4 percent of the groundwater resources.

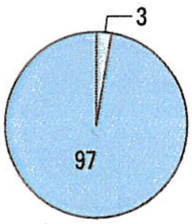
Most of the radioactivity in groundwater comes from the decay of naturally radioactive isotopes of uranium, thorium, and potassium in minerals in aquifer materials. Radioactive constituents were not present at high levels in the groundwater resources used for domestic drinking water. Gross alpha-particle activity and gross beta-particle activity were present at moderate levels in about 3 percent.

Nutrients, including nitrate, are naturally present at low concentrations in groundwater, but moderate and high concentrations generally indicate contamination from human activities. Common sources of nutrients include fertilizer applied to crops and landscaping, seepage from septic systems, and human and animal waste. Nitrate was not present at high concentrations in the groundwater resources used for domestic drinking water.

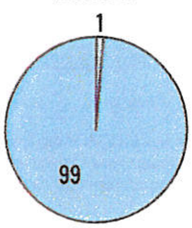
Trace elements



Uranium and radioactive constituents



Nitrate



Inorganic Constituents with Non-Health Benchmarks

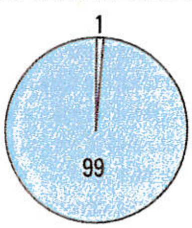
(Not included in water-quality overview charts shown on the front page)

Some constituents affect the aesthetic properties of water, such as taste, color, and odor, or can create nuisance problems, such as staining and scaling. The benchmarks used for these constituents were non-regulatory secondary maximum contaminant level benchmarks.

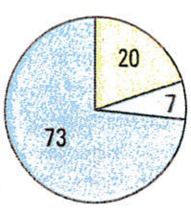
Total dissolved solids (TDS) concentration is a measure of the salinity of the groundwater, and all water naturally contains dissolved solids as a result of the weathering and dissolution of minerals in rocks and sediments. The State of California has a recommended and an upper limit for TDS in drinking water. Total dissolved solids were not present at high concentrations (greater than the upper limit), but was present at moderate concentrations (between the recommended and upper limits) in about 1 percent of the groundwater resources used for domestic drinking water.

Anoxic conditions (low amounts of dissolved oxygen) can result in the release of natural manganese, iron, and other associated trace elements from minerals into groundwater. Manganese or iron was present at high concentrations in about 20 percent of the groundwater resources used for domestic drinking water. In the entire Sierra Nevada, groundwater from wells in metamorphic rocks more commonly had high concentrations of manganese or iron than groundwater from wells in granitic, volcanic, or sedimentary rocks (Fram and Belitz, 2014). Over half of the wells sampled for the Yuba-Bear Watersheds were in metamorphic rocks.

Total dissolved solids

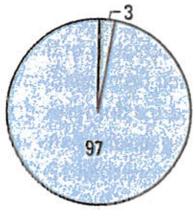


Manganese or iron

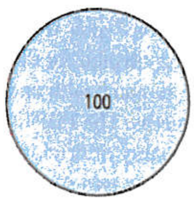


ORGANIC CONSTITUENTS

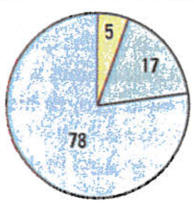
VOCs



Pesticides



E. Coli and total coliforms



Organic Constituents with Human-Health Benchmarks

The Priority Basin Project used laboratory methods that can detect concentrations of volatile organic compounds (VOCs) and pesticides that are below human-health benchmarks. The VOCs and pesticides detected at these very low concentrations can be used to help trace movement of water from the land surface into the aquifer system.

Volatile organic compounds, including solvents, gasoline components, and refrigerants, are contained in many household, commercial, and industrial products. No VOCs were detected at high concentrations in the groundwater resources used for domestic drinking water in the Yuba-Bear Watersheds, and VOCs were detected at moderate concentrations in about 3 percent. The VOCs detected at moderate concentrations were tetrachloroethene (PCE), trichloroethene (TCE), and toluene.

Pesticides, including herbicides, insecticides, and fumigants, are applied to crops, gardens, lawns, around buildings, and along roads to help control unwanted vegetation, insects, fungi, and other pests. Pesticides were not detected at high or moderate concentrations in the groundwater resources used for domestic drinking water. Low concentrations of herbicides or degradates of herbicides were detected in about 4 percent of the groundwater resources.

Microbial Indicators

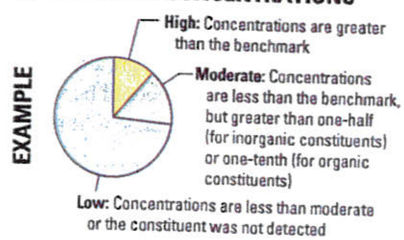
(Not included in water-quality overview charts shown on the front page)

Microbial indicators are used to evaluate the potential for fecal contamination of water sources. In the Yuba-Bear Watersheds, total coliforms and *Escherichia coli* (*E. coli*) were detected in 5 percent of the wells sampled, and total coliforms alone were detected in another 17 percent of the wells samples. Total coliforms are present naturally in soils and in digestive tracts of animals, whereas *E. coli* specifically indicate contamination with animal (or human) fecal waste (California State Water Resources Control Board, 2016).

METHODS FOR EVALUATING GROUNDWATER QUALITY

This study used comparison to benchmarks established for drinking water to provide context for evaluating the quality of groundwater. The quality of drinking water can differ from the quality of groundwater because of contact with household plumbing, exposure to the atmosphere, or water treatment. U.S. Environmental Protection Agency and California State Water Resources Control Board Division of Drinking Water regulatory benchmarks set for the protection of human health (maximum contaminant level, MCL) were used for comparison when available. Otherwise, non-regulatory benchmarks set for protection of aesthetic and technical properties, such as taste and odor (secondary maximum contaminant level, SMCL), and non-regulatory benchmarks set for the protection of human health (notification levels, NL, and lifetime health advisory levels, HAL) were used. Water quality in domestic wells is not regulated in California.

CONSTITUENT CONCENTRATIONS



Pie diagrams are used to summarize groundwater quality results. The pie slices represent the percentages of the groundwater resources with high, moderate, and low concentrations of a constituent. Methods for calculating these percentages are discussed by Fram and Belitz (2014).

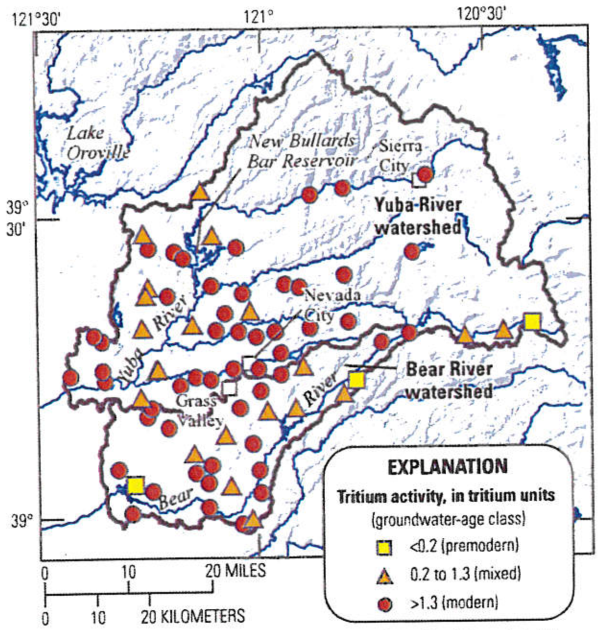
Benchmark type and value for selected constituents.

[**Benchmark type**: CA, State Water Resources Control Board Division of Drinking Water; EPA, U.S. Environmental Protection Agency; HAL, lifetime health advisory level; MCL, maximum contaminant level; NL, notification level; SMCL, secondary maximum contaminant level. **Abbreviations**: pCi/L, picocuries per liter; ppb, parts per billion or micrograms per liter (µg/L); ppm, parts per million or milligrams per liter (mg/L)]

Constituent	Benchmark		Constituent	Benchmark	
	Type	Value		Type	Value
Arsenic	EPA MCL	10 ppb	Nitrate, as nitrogen	EPA MCL	10 ppm
Barium	CA MCL	1,000 ppb	Total dissolved solids (TDS), upper and recommended	CA SMCL	1,000 ppm 500 ppm
Molybdenum	EPA MCL	40 ppb	Manganese	CA SMCL	50 ppb
Strontium	EPA HAL	4,000 ppb	Iron	CA SMCL	300 ppb
Vanadium	CA NL	50 ppb	Tetrachloroethene (PCE)	EPA MCL	5 ppb
Mercury	EPA MCL	2 ppb	Trichloroethene (TCE)	EPA MCL	5 ppb
Gross alpha-particle activity	EPA MCL	15 pCi/L	Toluene	CA MCL	150 ppb
Gross beta-particle activity	CA MCL	50 pCi/L			

Factors that Affect Groundwater Quality

Groundwater is generally a mixture of waters that recharged the aquifer system at different times. Groundwater 'age' — the time since the water was at the land surface — can range from less than 1 year to more than 50,000 years. The distribution of ages in a groundwater sample affects the water quality. Some constituents can be present at higher concentrations in older groundwater because of slow dissolution of minerals. Some constituents can be present at higher concentrations in groundwater with ages corresponding to particular times when human activities introduced contaminants to the recharged water. Preliminary groundwater ages based on tritium data for samples from the Yuba-Bear Watershed are summarized here.



Base modified from U.S. Geological Survey and other Federal and State digital data, various scales; Albers Equal-Area Conic projection, standard parallels are 29° 30' and 45° 30'; North American Datum of 1983

Tritium is a radioactive isotope of hydrogen that forms in the atmosphere naturally and in nuclear explosions and reactors. Atmospheric nuclear-weapons testing in the 1950s and 1960s increased tritium concentrations to far above natural levels. The tritium concentration in groundwater can be used to estimate whether the groundwater recharged before or after about 1950 (Jurgens and others, 2012). Two-thirds of the samples from the Yuba-Bear Watershed study unit had tritium concentration greater than 1.3 tritium units (TU), indicating they were "modern" (recharged after 1950). A few samples had tritium concentrations less than 0.2 TU, indicating they were "pre-modern" groundwater recharged before 1950, and the rest were mixtures of water recharged before and after 1950. Because most samples indicated relatively recent groundwater recharge, groundwater resources used for domestic supply in the Yuba-Bear Watersheds study unit could be vulnerable to water-quality changes resulting from human activities at the land surface and to relatively rapid depletion during periods of drought.

By Miranda S. Fram, Monica Jasper, and Kim A. Taylor

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Priority Basin Assessments

GAMA's Priority Basin Project (PBP) assesses water quality in groundwater resources used for public and domestic drinking-water supplies. This study in the Yuba and Bear River Watersheds in the Sierra Nevada focused on groundwater resources used for domestic drinking water. Ongoing assessments are being carried out in more than 120 basins and areas outside of basins throughout California. The PBP assessments compare constituent concentrations in untreated groundwater with benchmarks established for the protection of human health and for aesthetic concerns. The PBP does not evaluate the quality of drinking water.

The PBP uses two scientific approaches for assessing groundwater quality. The first approach uses a network of wells to statistically assess the status of groundwater quality. The second approach combines water-quality, hydrologic, geographic, and other data to help assess the factors that affect water quality. In the Yuba-Bear Watersheds study unit, data were collected by the PBP in 2015–16. The PBP includes chemical analyses not generally available as part of regulatory compliance monitoring, including measurements at concentrations much lower than human-health benchmarks and measurement of constituents that can be used to trace the sources and movement of groundwater.

For more information

Technical reports and hydrologic data collected for the GAMA Program may be obtained from:

GAMA Project Chief
U.S. Geological Survey
California Water Science Center
6000 J Street, Placer Hall
Sacramento, CA 95819
Telephone number: (916) 278-3000
WEB: *http://ca.water.usgs.gov/gama*

GAMA Program Unit Chief
State Water Resources Control Board
Division of Water Quality
PO Box 2231, Sacramento, CA 95812
Telephone number: (916) 341-5855
WEB:
http://www.waterboards.ca.gov/gama

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Groundwater Nitrate Sources and Contamination in the Central Valley

Posted on September 17, 2017 by UC Davis Center for Watershed Sciences

by Katherine Ransom and Thomas Harter

In California's Central Valley, many communities depend significantly or entirely on groundwater as their drinking water supply. Studies estimate the number of private wells in the Central Valley to be on the order of 100,000 to 150,000 (Viers et al., 2012; Johnson and Belitz, 2015).

Elevated nitrate concentrations in groundwater can be a problem for private well owners, community service districts, and municipalities who rely on groundwater wells. Drinking water with a nitrate concentration greater than 10 mg/L NO_3-N (the drinking water standard known as the maximum contaminant level, or MCL) has been linked to health effects such as low infant blood oxygen levels, miscarriage, and certain cancers.

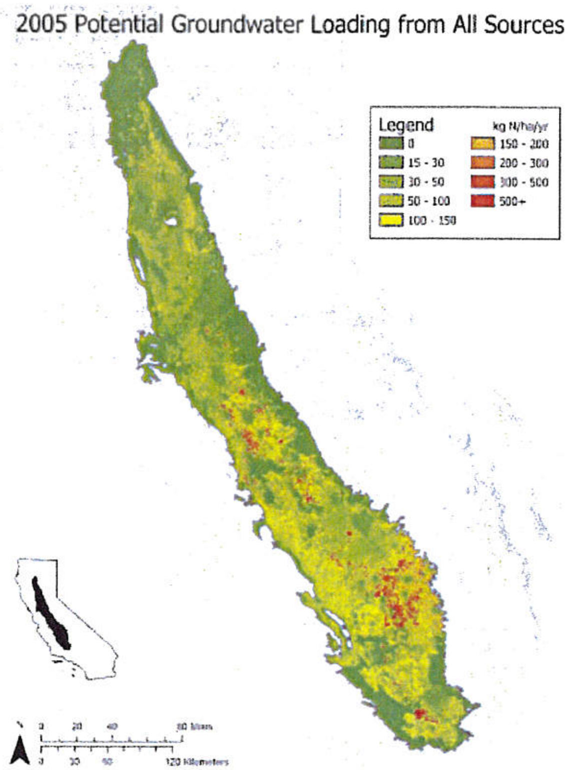
We recently completed several studies that show the extent of nitrate contamination in shallow groundwater and the likely sources of the contamination in the Central Valley. The results show that, at the private well depth, a relatively small area is predicted to exceed the MCL, but a large portion of the valley is predicted to have elevated nitrate (at the 5 mg/L rate, a concentration considered to indicate elevated nitrate levels from human impacts). The public well depth is overall less at risk, but still has a decent amount of area predicted to exceed 5 mg/L.

The Central Valley is a highly productive agricultural region with approximately 7 million of California's nearly 9 million acres of irrigated farmland (California Department of Water Resources, Agricultural Land and Water Use Estimates, 2010). In addition, over 80% of California's 1.8 million adult cows live on dairies in the Central Valley.

Nitrate is a naturally occurring form of nitrogen, but is also created in areas with excess fertilizer, manure, urban and food processing waste effluent applications, or septic leach fields spaced at high density. Much of the excess nitrogen (N) is converted to nitrate, which eventually makes its way into groundwater where it can persist for decades or even centuries – a process known as nitrogen leaching.

We estimate that 550 thousand tons of N fertilizer, 240 thousand tons of manure N, and 4 thousand tons of urban and food processing waste effluent N are annually applied to or recycled in Central Valley agricultural lands for food production. About 130 thousand tons of N are fixed from atmospheric nitrogen directly by leguminous crops (mostly alfalfa). While harvest removes about half of the nearly one million tons of N input to cropland, and some nitrogen is lost to the atmosphere, about 360 thousand tons N per year is potentially leaching to groundwater from agricultural lands.

Other sources in the Central Valley are estimated to leach 20-25 thousand tons N to groundwater (urban areas: 10, municipal wastewater and food processing percolation basins: 4, dairy lagoons and animal holding areas: 6, and septic leach fields: 3). Manure production has increased exponentially since the middle of the 20th century through the mid-2000s, when dairy cow numbers levelled off. In contrast, fertilizer use increased predominantly in the decades after World War II and has largely levelled off since the late 1980s. Crop production has continued to increase steadily over the past 70 years (Harter et al., 2012; Tomich et al., 2016; Harter et al., 2017).

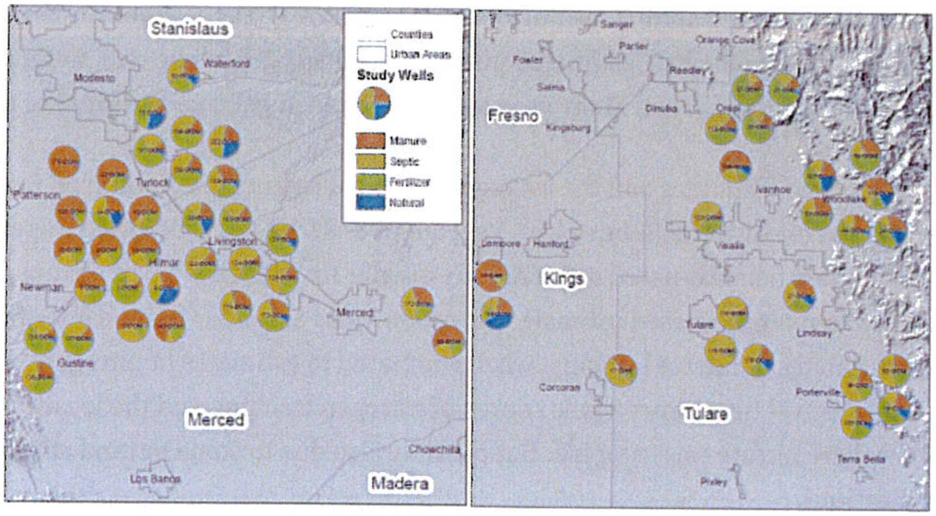


Estimated potential groundwater nitrate-nitrogen loading from cropland (not including alfalfa, left); and from alfalfa, urban areas, golf courses, dairy corrals, and wastewater/manure lagoons (right) in the Central Valley in the mid-2000s. Cropland leaching was estimated using a mass balance approach. Other leaching was based on reported nitrogen fluxes, measured leaching rates, or estimated from surveys. 1 kg N/ha/year = 0.9 lb N/acre/year (Harter et al., 2017).

Land use, nitrate leaching, and domestic groundwater

The amount of nitrate that leaches to groundwater (nitrogen loading rate) can be highly variable between different crop or land use types and among an individual crop or land use. This is due to differences in crop nutrient demands, soil and climate properties, and farm management techniques. Most measurements of nitrogen loading from crops are based on a few field studies performed over 30 years ago. The above estimates of potential nitrogen loading to groundwater are based on reports of N applications and N removal to harvest for nearly 60 different crops and on research about atmospheric N losses and other nitrogen pathways. But independent confirmation of estimates that are based on actually measured groundwater nitrate data has been lacking.

We performed a Central Valley analysis of domestic well nitrate data to relate groundwater nitrate to surrounding land uses and to estimate the amount of nitrogen loading from 15 crop and land use groups. This study focused exclusively on data from private domestic wells since they are typically more shallow and more likely to show impacts from more recent (5-30 years ago) surface activities on water quality. A database of recent nitrate measurements (past 15 years) from 2,149 private wells was assembled and the land use surrounding each well was determined (Ransom et al., 2018). Using these data, we estimated a range of likely loading rates for each crop or land use type.



Estimated amount of nitrate from each of the four sources, as percent of total, for each study well. Wells with overlapping pie charts were offset to prevent overlap.

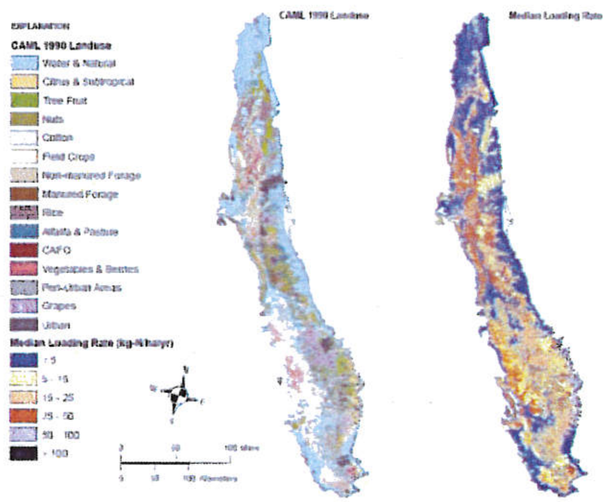
Concentration of contamination

Finally, a joint effort between UC Davis and the USGS resulted in a high resolution estimation of nitrate concentrations across the Central Valley, at the average depth of a private domestic well and, separately, for the average depth of public supply wells (Ransom, et al. 2017). These maps were developed by considering 146 mapped variables that potentially relate to the risk for groundwater nitrate contamination. These included soil and climatic variables, and recent estimates of groundwater age, nitrogen accounting, and groundwater chemistry.

The 146 maps were compared to nitrate measurements from over 5,000 private and public wells, taken during the past 15 years. Using a machine-learning algorithm to find patterns in the data, we created a ranking of which variables were the most likely to affect groundwater nitrate concentrations at the two depths. Among the 146 mapped variables, groundwater chemistry related to denitrification, historical nitrogen application amounts in agriculture, groundwater age, well distance to rivers, and amount of natural land use surrounding wells (among others) were rated as the most important to determine a location's nitrate concentration.

Results of the study indicate confined animal feeding operations (dairies), citrus & subtropical crops, and vegetable & berry crops to have the highest estimated nitrogen loading rates, while rice, water & natural land use, and alfalfa & pasture crops have the lowest. Many crop and land use groups have overlapping estimated ranges.

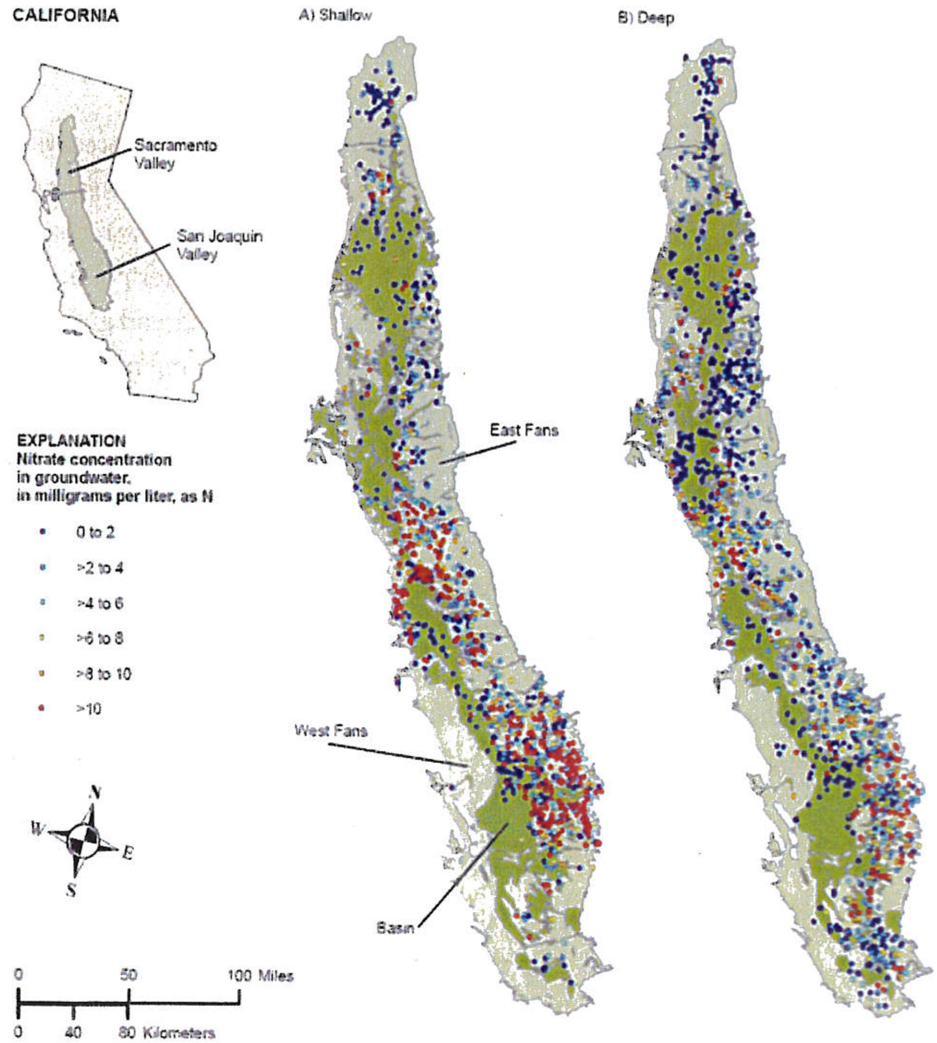
The groundwater nitrate-based estimates and the average potential leaching rates obtained from mass balance analysis are fairly consistent for Citrus & Subtropical, Vegetables & Berries, Field crops, Grapes, and the Water & Natural group. However, mass balance-based estimates are greater for Manured Forage crops, Nuts, Cotton, Tree Fruit, and Rice. Groundwater-nitrate-based estimates for urban areas and CAFOs appear largely consistent with reported data. Lower estimates of nitrate leaching, when compared to estimates of nitrogen loading, are partially due to the (multi-)decadal travel time between the source of nitrogen leaching and the location of domestic or other production wells where nitrate was sampled. But possibly also due to some natural attenuation of nitrate in groundwater (denitrification).



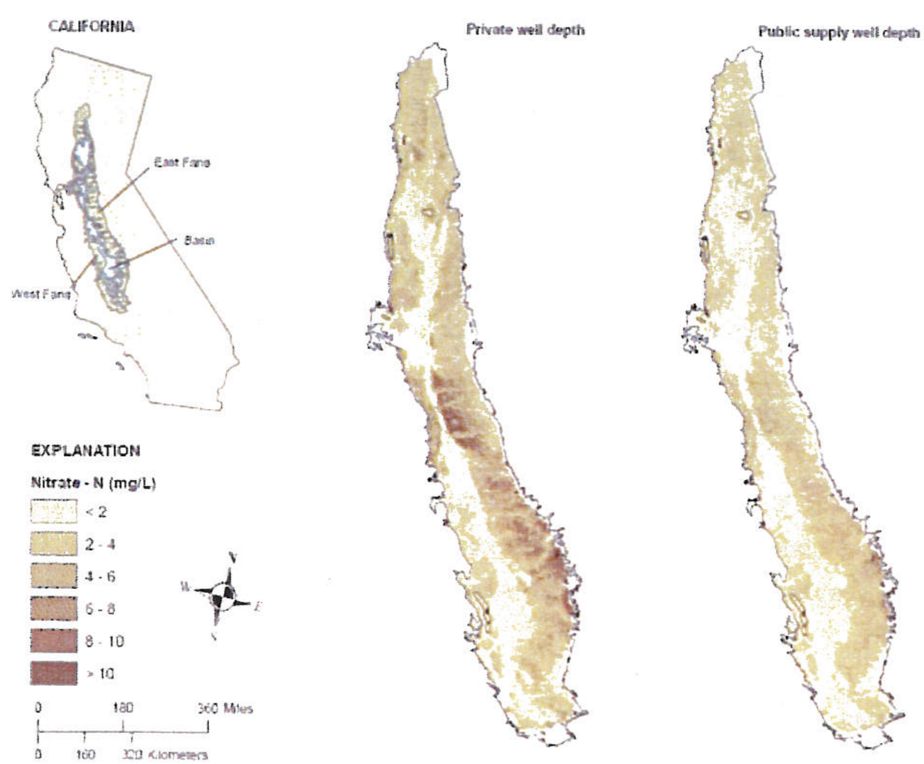
Land use from the CAML data set for the 15 crop and land use groups used in the study and the same crop and land use groups keyed to the median estimated nitrogen loading rate in kg N ha-1 yr-1 for the corresponding group (right side).

Identifying nitrate sources

Other sources besides manure and fertilizer may also contribute to groundwater nitrate concentration, including septic waste and natural sources (though natural sources typically contribute very minimal amounts.) Also, the amount of nitrate in an individual well is often the result of several nitrate sources. We quantified the amount of nitrate from each of four sources (manure, fertilizer, septic, and natural) in 56 private wells in the San Joaquin Valley ([Ransom et al., 2016](#)). Results of this "fingerprinting" study indicate that multiple nearby sources have likely contributed to an individual well's nitrate concentration; it also shows some regional patterns in groundwater nitrate sources: manure sources are often more dominant in private wells located in dairy regions such as Hilmar, while fertilizer sources are more dominant in the citrus crop regions of Orosi and Woodlake. Septic system sources were shown to be a dominant source in some wells on the outskirts of urban centers where septic system density is high. The study also demonstrates that – without detailed site-specific investigations – significant uncertainty exists about a specific nitrate source's contribution to the nitrate measured in a particular drinking water well.



Well locations of wells used in [Ransom et al. (2017)] color coded by well nitrate concentration (3508 wells total) for shallow (1400 wells, mostly private) and deep (2108 wells, mostly public supply) zones.



Prediction of groundwater nitrate at median depths of private and public supply wells (54.86 m and 121.92 m, respectively). Unmapped (white) area within the Central Valley boundary was due to missing data.

Efforts are ongoing by agriculture and State of California agencies to better control sources of nitrate contamination through improved crop nitrogen management, while also developing programs to support affected communities with drinking water treatment and alternative supplies. These programs recognize that nonpoint source pollutants require an approach that is different from traditional groundwater pollution programs given the large number and broad distribution of nitrate sources, and the resulting wide-spread groundwater nitrate pollution. Our work supports the strategy taken by these efforts, which focus on regional source control and more support for drinking water treatment and alternative supplies. With this research, we hope to highlight areas where nitrate contamination is most likely to be elevated, provide further evidence for the regional scale contribution from various nitrate sources, and help focus nutrient management and educational efforts.

Katherine Ransom graduated in June 2017 with a PhD from the University of California Davis, Hydrologic Sciences Graduate Group. Her work has focused on statistical models of groundwater contamination. She is currently working as a postdoctoral researcher with the United States Geological Survey through UC Davis on predicting and mapping groundwater parameters in the Great Lakes region. Thomas Harter is a groundwater expert at the University of California, Davis.

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4 Responses to *Groundwater Nitrate Sources and Contamination in the Central Valley*

Frances Griffin *says:*
September 17, 2017 at 11:01 pm

At Lake Tahoe, the creek with the beaver dam on it had a lower level of nitrates than the creek not filtered by a beaver dam.

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Reply

Naturale Desalination *says:*
September 18, 2017 at 11:03 am

CENTRAL VALLEY SALINITY ALTERNATIVES FOR LONG TERM SUSTAINABILITY (CV-SALTS)

Region 5: Updated Groundwater Quality Analysis and High Resolution Mapping for Central Valley Salt and Nitrate Management Plan

JUNE 2016

Prepared for

SAN JOAQUIN VALLEY DRAINAGE AUTHORITY

Submitted by

LUHDORFF AND SCALMANINI CONSULTING ENGINEERS

In association with

LARRY WALKER ASSOCIATES, INC

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

LARRY WALKER ASSOCIATES

Table 14 Region 5: DWR Bulletin 118 Groundwater Basins/Subbasins Aggregate (Volume- Weighted) Ambient Conditions for Nitrate (as N) and TDS

Aggregate (Volume Weighted) Ambient Conditions

		Nitrate (mg/L as N)			TDS (mg/L)		
	DWR B118 Groundwater Basin Code	Upper Zone	Lower Zone*	Production Zone	Upper Zone	Lower Zone*	Production Zone
Northern Central Valley	5-6.01	1.04	1.05	1.05	164	178	172
	5-6.02	0.95	1.36	1.16	149	202	176
	5-6.03	1.03	1.21	1.12	190	147	168
	5-6.04	0.99	1.45	1.22	258	159	198
	5-6.05	0.92	1.76	1.28	148	160	154
	5-6.06	0.85	0.89	0.87	162	192	176
	5-21.50	1.37	1.88	1.67	238	238	238
	5-21.51	1.78	2.34	2.16	289	264	272
	5-21.52	3.29	2.87	3.06	613	472	533
	5-21.53	1.23	2.20	1.77	234	262	250
	5-21.54	1.92	3.06	2.66	361	297	320
	5-21.55	1.59	1.91	1.80	226	223	224
	5-21.56	2.42	1.36	1.67	200	181	186
	5-21.57	2.83	2.08	2.28	204	192	195
	5-21.58	2.62	1.38	1.80	403	313	343
	5-21.59	1.93	0.99	1.31	338	310	320
	5-21.60	2.19	2.35	2.28	349	295	317
	5-21.61	2.91	1.90	2.30	430	365	391
	5-21.62	2.37	1.15	1.67	992	918	950
	5-21.64	3.67	1.58	2.37	446	298	353
	5-21.67	12.27	3.59	7.63	790	523	647
	5-21.68	2.66	6.03	4.58	1069	635	823
Middle Central Valley	2-3	3.48	3.47	3.47	1400	564	900
	2-4	4.82	1.07	2.68	2896	671	1628
	5-21.65	2.13	1.55	1.78	343	222	270
	5-21.66	4.46	2.68	3.36	935	504	669
	5-22.01	6.07	3.69	4.72	506	293	385
	5-22.02	7.58	3.74	5.53	352	217	280
	5-22.03	10.97	4.63	7.74	439	211	322
	5-22.04	6.48	3.46	4.85	418	261	334
	5-22.05	8.88	6.64	8.21	874	540	774
	5-22.06	4.65	3.78	4.09	417	275	325
	5-22.07	5.84	3.32	5.01	1307	928	1184
	5-22.15	3.64	2.30	3.04	1255	890	1091
	5-22.16	2.65	1.48	1.87	206	227	220
Southern Central Valley	5-22.08	7.12	6.62	6.84	560	391	464
	5-22.09	1.26	2.86	1.80	2038	1165	1744
	5-22.10	2.32	0.43	1.37	3218	846	2025
	5-22.11	11.88	13.38	12.64	514	419	465
	5-22.12	5.33	1.36	3.23	1659	740	1173
	5-22.13	8.31	8.29	8.30	588	382	465
	5-22.14	5.54	3.29	3.76	2313	561	1177

*Above Corcoran Clay where present.

Table 16 Central Valley Floor, Initial Analysis Zones Aggregate (Volume-Weighted) Ambient Conditions for Nitrate (as N) and TDS

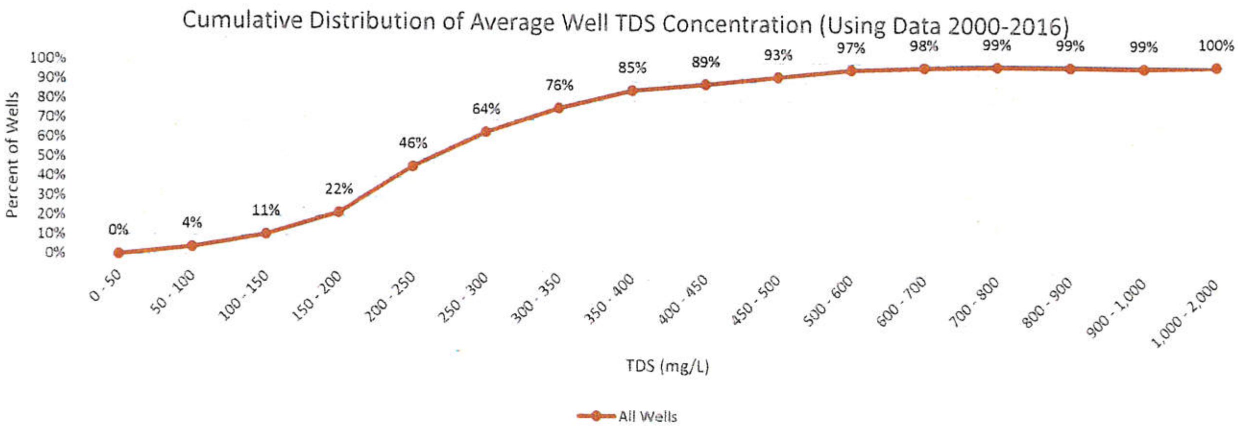
Aggregate (Volume Weighted) Ambient Conditions

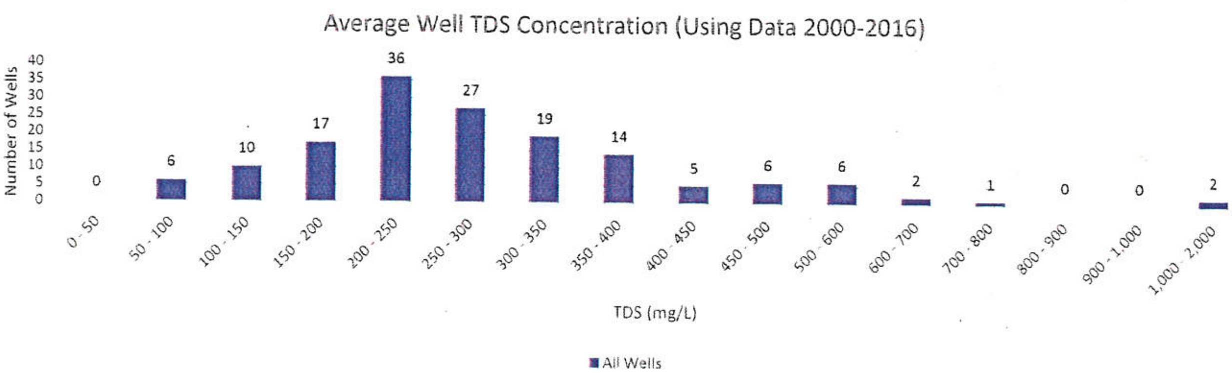
		Nitreate (mg/L as N)			TDS (mg/L)		
	IAZs	**Upper Zone**	**Lower Zone***	**Production Zone**	**Upper Zone**	**Lower Zone***	**Production Zone**
Northern Central Valley	**1**	1.01	1.23	1.12	180	169	159
	2	1.92	2.15	2.07	250	236	240
	3	3.77	3.17	3.42	645	486	551
	4	1.49	0.96	1.20	747	657	698
	5	2.48	1.44	1.81	433	360	386
	6	6.06	3.60	4.58	914	524	682
	7	3.76	1.60	2.40	431	289	342
Middle Central Valley	**8**	3.29	2.38	2.71	249	222	232
	9	5.23	1.53	3.36	1091	627	858
	10	6.90	6.69	6.82	1087	767	966
	11	9.24	4.71	6.87	479	241	354
	12	10.90	4.61	7.72	446	212	328
	13	6.06	3.78	4.78	505	297	388
	22	6.12	2.36	4.94	1357	984	1240
Southern Central Valley	**14**	1.26	2.71	1.76	2077	1148	1761
	15	4.96	2.40	3.65	1442	717	1071
	16	6.49	5.46	5.88	373	254	302
	17	10.01	9.36	9.63	413	318	357
	18	9.97	10.51	10.26	569	398	475
	19	6.27	1.43	3.21	3988	841	2573
	20	4.93	4.41	4.54	502	412	436
	21	3.18	2.88	2.93	668	564	593

*Above Corcoran Clay where present.

Wells in the AEM Study Area (with a 1-mile buffer)

	TDS (mg/L)
	All Wells
Number of Wells	151
Mean	297
Median	268
Maximum	1,600
Standard Deviation	182
Coefficient of Variation	61
Skewness	4
75th Percentile	348
95th Percentile	525
99th Percentile	1,057

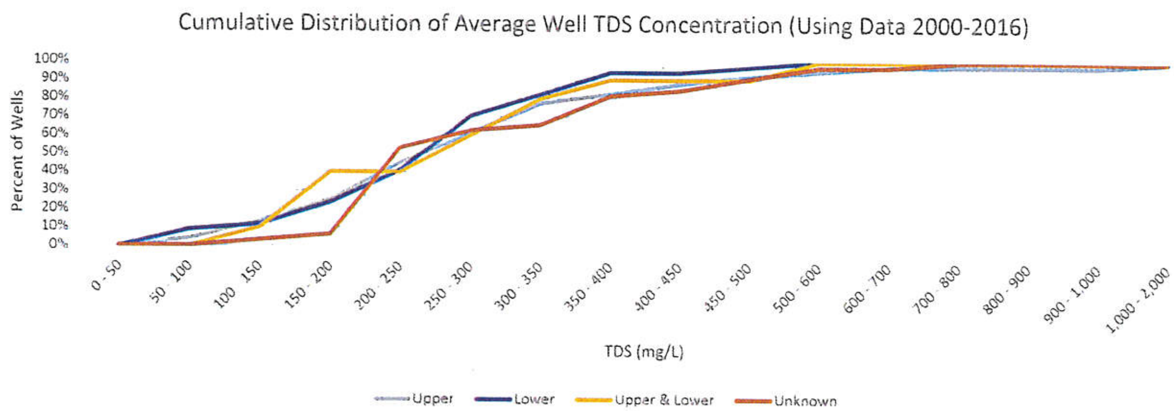


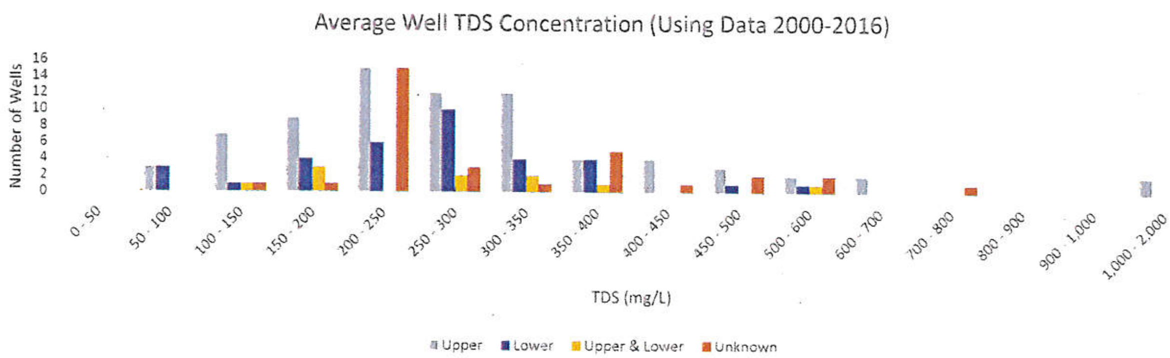


Wells in the AEM Study Area (with a 1-mile buffer)

TDS (mg/L)

	Upper Zone	Lower Zone	Upper & Lower Zones	Unknown
Number of Wells	75	34	10	32
Mean	310	262	275	312
Median	269	270	281	243
Maximum	1,600	511	505	779
Standard Deviation	229	101	111	136
Coefficient of Variation	74	39	40	44
Skewness	4	0	1	2
75th Percentile	342	314	328	384
95th Percentile	599	414	440	524
99th Percentile	1,405	497	492	704





1 INTRODUCTION

Consistent with the overarching goals of the Central Valley Salinity Alternatives for Long Term Sustainability (CV-SALTS) and the Recycled Water Policy (RWP) for the State of California, CV-SALTS is developing a comprehensive Salt and Nitrate Management Plan (Central Valley SNMP or SNMP) for the Central Valley Regional Water Quality Control Board's (Central Valley Water Board's) jurisdictional boundaries (Central Valley region or Region 5). There are 126 basins/subbasins in Region 5, including 41 groundwater basins/subbasins (as defined by the California Department of Water Resources' [DWR's] Bulletin 118 (DWR B118) overlying the Central Valley Floor) and 85 basins/subbasins that are located outside the Central Valley Floor. The entire Region 5 area covered by groundwater basins is about 24,100 square miles; the area of the 41 basins/subbasins in the Valley Floor is about 20,500 square miles, or about 85% of the total groundwater basins/subbasins within Region 5. These basins and subbasins are shown in **Figure 1**. More information about each basin can be found in DWR's B118 as available[1].

One of the overarching goals of the State RWP is to develop salt and nutrient management plans that are sustainable over the long-term and that promote clean, abundant, local water by emphasizing water recycling, water conservation, and stormwater recharge. It is the intent of the RWP that local stakeholders work collaboratively to fund and develop locally driven SNMPs for each groundwater basin/subbasin in California.

The SNMP will identify the approach while establishing the basis for the short and long-term management strategies of salt and nitrate in the Central Valley region. It is anticipated that, upon adoption of the Central Valley SNMP, local-scale SNMPs will be developed and implemented by local and/or regional stakeholder groups/entities, as needed. It is intended that the local SNMPs will be informed by prototype and archetype methods developed by CV-SALTS and guided by the implementation measures and structure recommended in the final, adopted Central Valley SNMP.

It is the intent of the RWP that local stakeholders work collaboratively to fund and develop locally driven SNMPs for each groundwater basin/subbasin in California. Specific goals identified by the RWP, and adapted for CV-SALTS, include:

- Facilitate the development of local SNMPs that are consistent and/or integrated with the Central Valley SNMP;
- Support increased recycled water use in the region;
- Support the use of stormwater recharge as a water management measure;
- Maintain a reliable, high-quality water supply by protecting the beneficial uses of groundwater;
- Balance the use of assimilative capacity and the implementation of management measures within the region; and

[1] http://www.water.ca.gov/ground water/bulletin118/index.cfm

- Monitor the implementation of SNMPs to determine if desired outcomes are being achieved.

The SNMP provides the overarching framework, including default identification of current ambient water quality and available assimilative capacity for the entire Central Valley.

Luhdorff & Scalmanini, Consulting Engineers (LSCE) in association with Larry Walker Associates (LWA) have prepared this Technical Memorandum that updates the groundwater quality analyses for the Central Valley Floor using high resolution techniques as described in the Phase II Preliminary Draft Central Valley SNMP Appendix C (LWA, LSCE et al., 2016).This Technical Memorandum also expands on the groundwater quality analyses for Region 5 and extends mapping and analyses to include groundwater basins and subbasins in Region 5 that are located outside the Central Valley Floor.

The preparation of high resolution groundwater quality maps for three defined groundwater zones (Upper, Lower, and Production Zones; see **Section 2** for more explanation of the Zone delineation) throughout the Central Valley Floor provides a more refined and accurate characterization of the ambient groundwater quality and assimilative capacity than what was provided previously as a part of the aggregated Initial Analysis Zones (IAZ) analysis with the CV-SALTS Phase I Initial Conceptual Model (ICM; LWA, LSCE et al., 2013). The high resolution detail will facilitate regional salt and nitrate management for the entirety of Region 5's jurisdiction, including the planning and implementation of long-term strategies and assessment of interim measures.

The high resolution groundwater quality maps also provide the background information for identifying monitoring data gaps and for developing future groundwater quality monitoring programs. The updated groundwater quality analyses and mapping in this Technical Memorandum provide preliminary local-scale information, which can be refined by local and/or regional entities as needed.

1.1 Background

The groundwater quality data collected, compiled, checked, and documented for CV-SALTS Phase I ICM were updated as part of the CV-SALTS Phase II Conceptual Model, Task 3. However, the original scope of work for the Phase II Preliminary Draft SNMP did not include additional analyses to update the ICM results. Also, the Phase I ICM analysis was limited in spatial coverage and groundwater quality characterization to within the Central Valley Floor.

The ICM work involved defining zones (Initial Analysis Zones, or IAZs; see **Figure 3**) for purposes of conducting the preliminary water, salt, and nitrate balances for the Central Valley. **Figure 4** shows the relationship between the DWR B118 subbasins in the Central Valley Floor and the IAZs. During the ICM work, it was reported that, in the context of groundwater sustainability for an aquifer system, no definition of assimilative capacity exists in the State RWP or elsewhere. Therefore, a preliminary definition for assimilative capacity pertaining to groundwater was provided[2]. Correspondingly, a

[2] The SWRCB Recycled Water Policy refers to assimilative capacity, however, an explicit definition is not provided in that guidance document. For ICM purposes, assimilative capacity was defined as the amount of a constituent (contaminant load) that can be discharged to the aquifer system (especially that part of the aquifer system that provides actual or probable beneficial uses) without exceeding water quality standards and/or Basin Plan water quality objectives. Additionally, this term describes the difference between the water quality standards/objectives and average ambient shallow groundwater quality in the basin/subbasin/IAZ/MZ (where shallow does not

shallower part of the aquifer system (20-year vertical travel depth in the saturated part of the aquifer system, i.e., called the *shallow zone* in the ICM) was also defined as the vertical boundary for this purpose. The ICM results for ambient groundwater quality and preliminary assimilative capacity are based on the aggregated scale of each IAZ shallow zone. Based on the preliminary definition of assimilative capacity for the ICM, the "shallow" zone constituted the "part of the aquifer system that provides actual or probable beneficial uses." At that time, the focus was on the depth at which individual (private) water supply wells might typically be constructed. Since the ICM work, the Management Zone (MZ) construct has evolved to extend the interpretation of the aquifer system; the refined interpretation of aquifer zone delineation is provided in **Section 2** of this Technical Memorandum.

The original scope of work for the Phase II Preliminary Draft Central Valley SNMP relied on the following:

- Aggregated scale of analysis of ambient groundwater quality (nitrate and TDS) and assimilative capacities for the IAZ shallow zone, which were based on the earlier ICM groundwater quality data along with QA/QC concerns and data limitations identified at the time of the ICM work;
- Preliminary aggregated scale of analysis of assimilative capacity (nitrate and TDS) for the IAZ shallow zone;
- An updated groundwater quality database (but no scope to conduct updated analyses); and
- Management Zone archetype analyses of ambient water quality and assimilative capacity for the Alta Irrigation District.

Subsequently, the work conducted for this Technical Memorandum updates the groundwater quality analyses for the Central Valley Floor using high resolution techniques as described in the Preliminary Draft Central Valley SNMP Appendix C and expands the analyses to include basins and subbasins in Region 5 that are located outside the Central Valley Floor. The work summarized in this Technical Memorandum includes:

- Combining the Phase II Preliminary Draft Central Valley SNMP, Task 3 groundwater quality database with additional data in the State Water Board's Division of Drinking Water database for purposes of the higher resolution analyses[3];
- Preparing basic statistical analyses, including minimum, maximum, average (or mean) and median values for nitrate and TDS, for the 41 groundwater basins/subbasins overlying the Central Valley Floor (and for the other 85 basins/subbasins in Region 5 that are located outside the Central Valley Floor);

necessarily mean the uppermost part of the saturated zone directly at the water table, rather "shallow" means the part of the aquifer system that provides actual or probable beneficial uses).

[3] The State Water Board authorized use of the confidential well construction and accurate location information contained in the Division of Drinking Water database for purposes of the Alta Irrigation District archetype analyses. These data improve the categorization of the groundwater quality data relative to their representation of groundwater quality for different parts of the aquifer system. Although the use of the data enhances the overall results, the confidentiality agreement will be maintained and the data will not be directly disclosed unless the team is otherwise directed by the State Water Board and the CV-SALTS Contract Administrator.

- Defining Upper and Lower Zones for the groundwater system in the Central Valley Floor[4]. For SNMP purposes, the Upper Zone together with the Lower Zone represent the Production Zone where the majority of groundwater production occurs;
- Preparing high resolution ambient groundwater quality maps (nitrate and TDS) for the Central Valley Floor (for three defined zones: Upper, Lower, and Production Zones) and for basins/subbasins outside the Central Valley where sufficient data are available;
- Preparing high resolution assimilative capacity maps (nitrate and TDS) for the Central Valley Floor (Upper, Lower, and Production Zones) and for basins/subbasins outside the Central Valley where sufficient data are available;
- Preparing trends and estimated future groundwater quality conditions maps; and
- Providing information for the Preliminary Draft Central Valley SNMP that serves as the programmatic basis for SNMP purposes for basins/subbasins in Region 5. The updated groundwater quality data analyses also provide a basis for future assessment of local and regional data gaps and monitoring needs.

Subsequent sections of and attachments to this document are organized as follows:

Section 2 provides an explanation of the approach used to delineate the Upper and Lower Zones of the aquifer system, including consideration of the Corcoran Clay where present. The approach for calculating Production Zone conditions, based on a volume-weighted combination of the Upper and Lower Zones, is also described.

Section 3 provides basic well statistics for each of the DWR B118 groundwater basins within Region 5 and the IAZs within the Central Valley Floor. Statistics provided for each boundary include the minimum/maximum/average/median concentrations and the number of wells that have well construction information. This section also provides brief descriptions of the methodologies used for estimating ambient conditions, assimilative capacity, trends, and estimated future groundwater quality conditions. Also addressed are the methods for calculating aggregated results.

Attachment includes zoomed-in maps at the DWR B118 basin/subbasin scale for basins/subbasins located in the Central Valley Floor and outside the Central Valley Floor where sufficient nitrate and TDS data are available. These maps depict ambient groundwater quality, assimilative capacity, groundwater quality trends, and estimated future groundwater quality conditions (at 10, 20 and 50 years) for the Upper, Lower, and Production Zones and below the Corcoran Clay as applicable. Similar zoomed-in maps are included for the IAZ scale, as applicable.

[4] See additional explanation in Section 2.

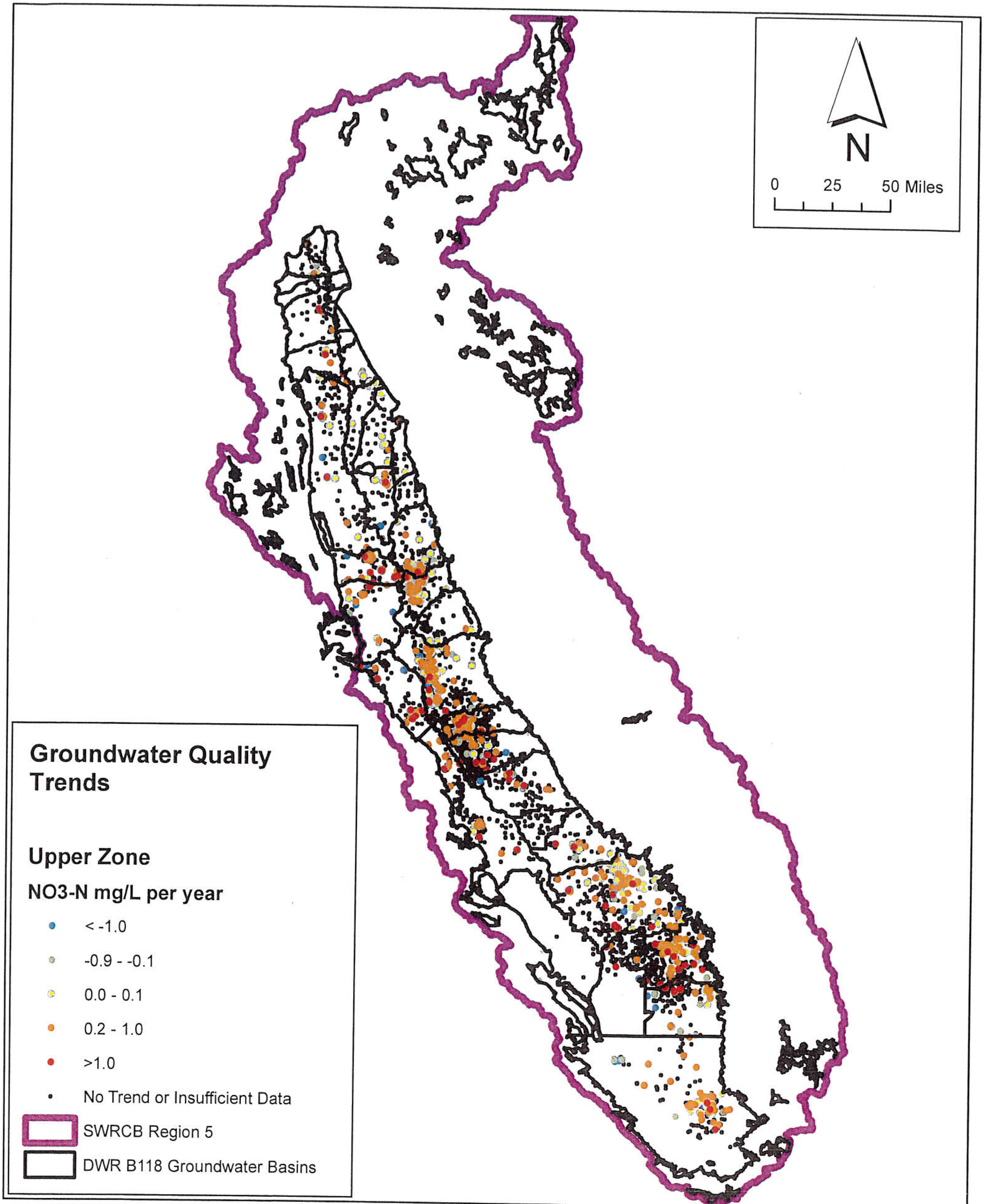


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Figure 96

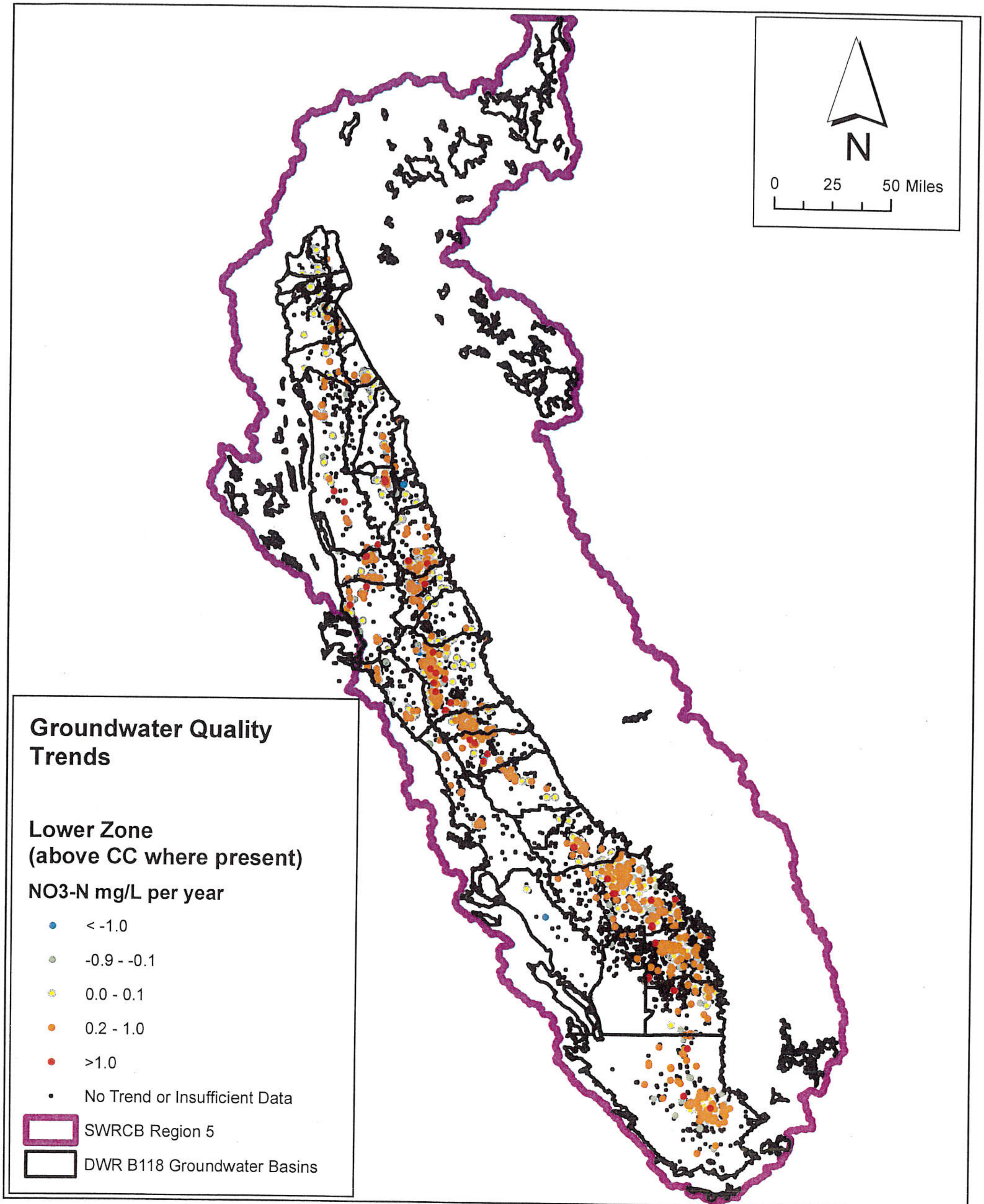

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Figure 97

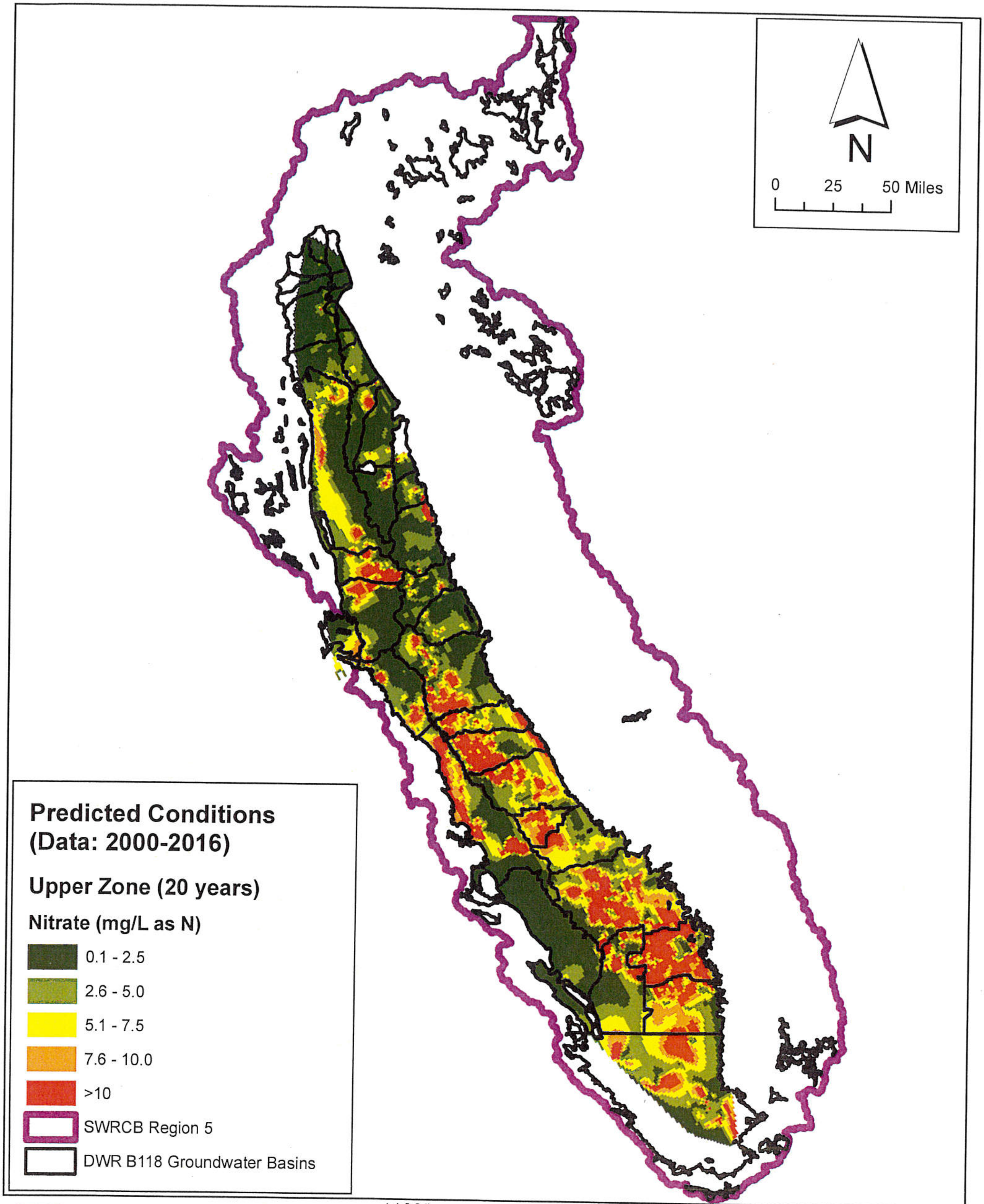

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Figure 105

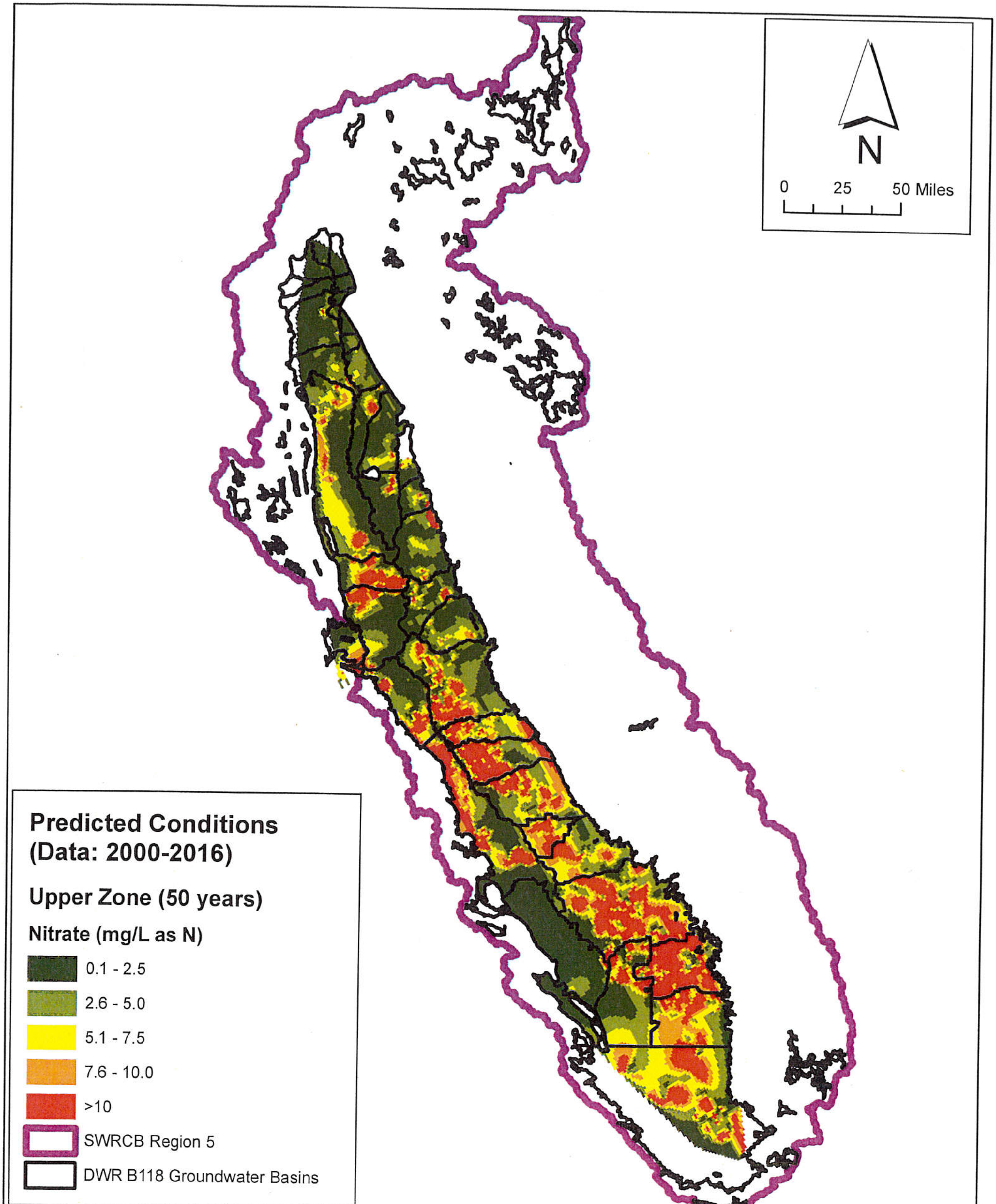

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Figure 106

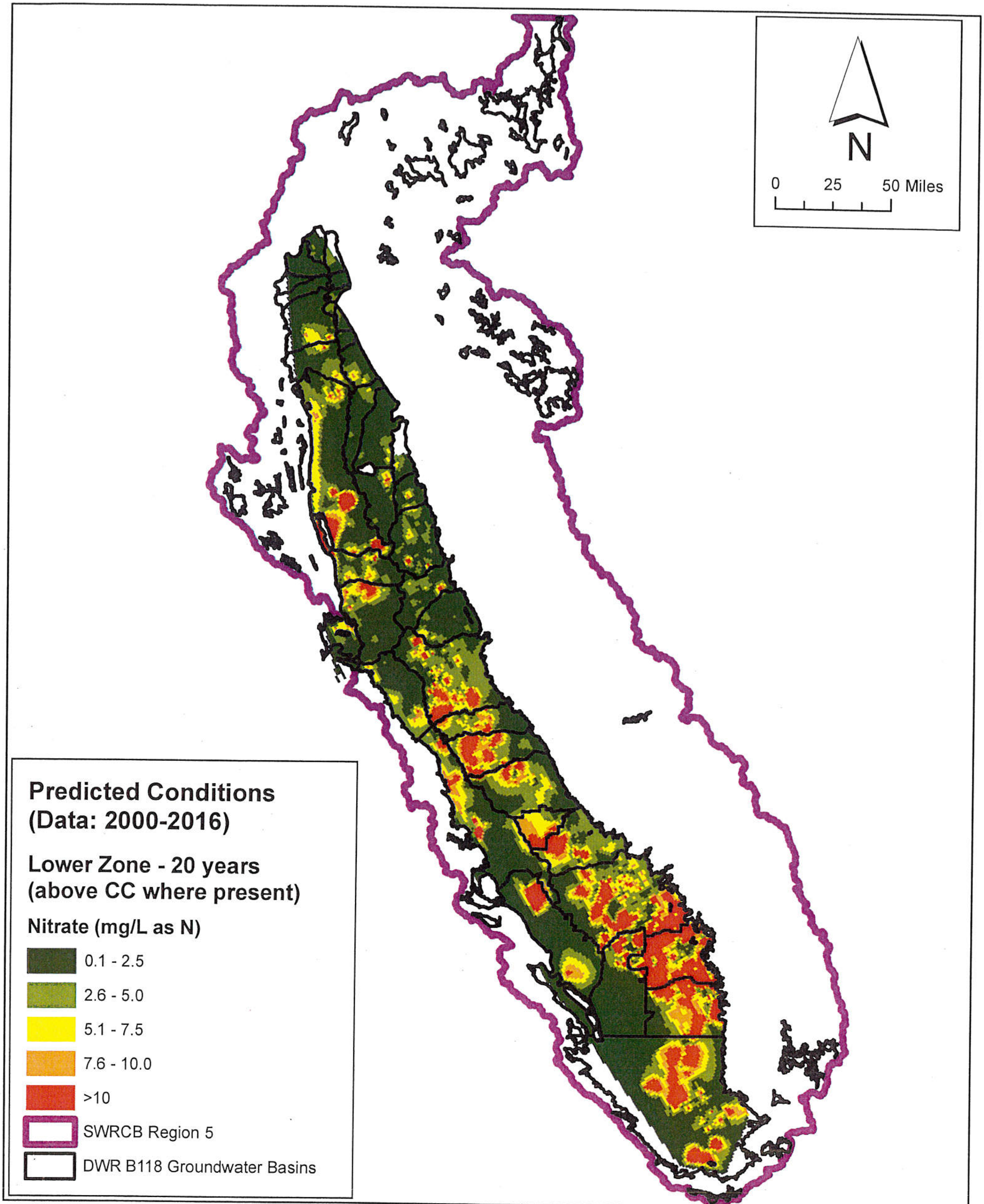

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Figure 108

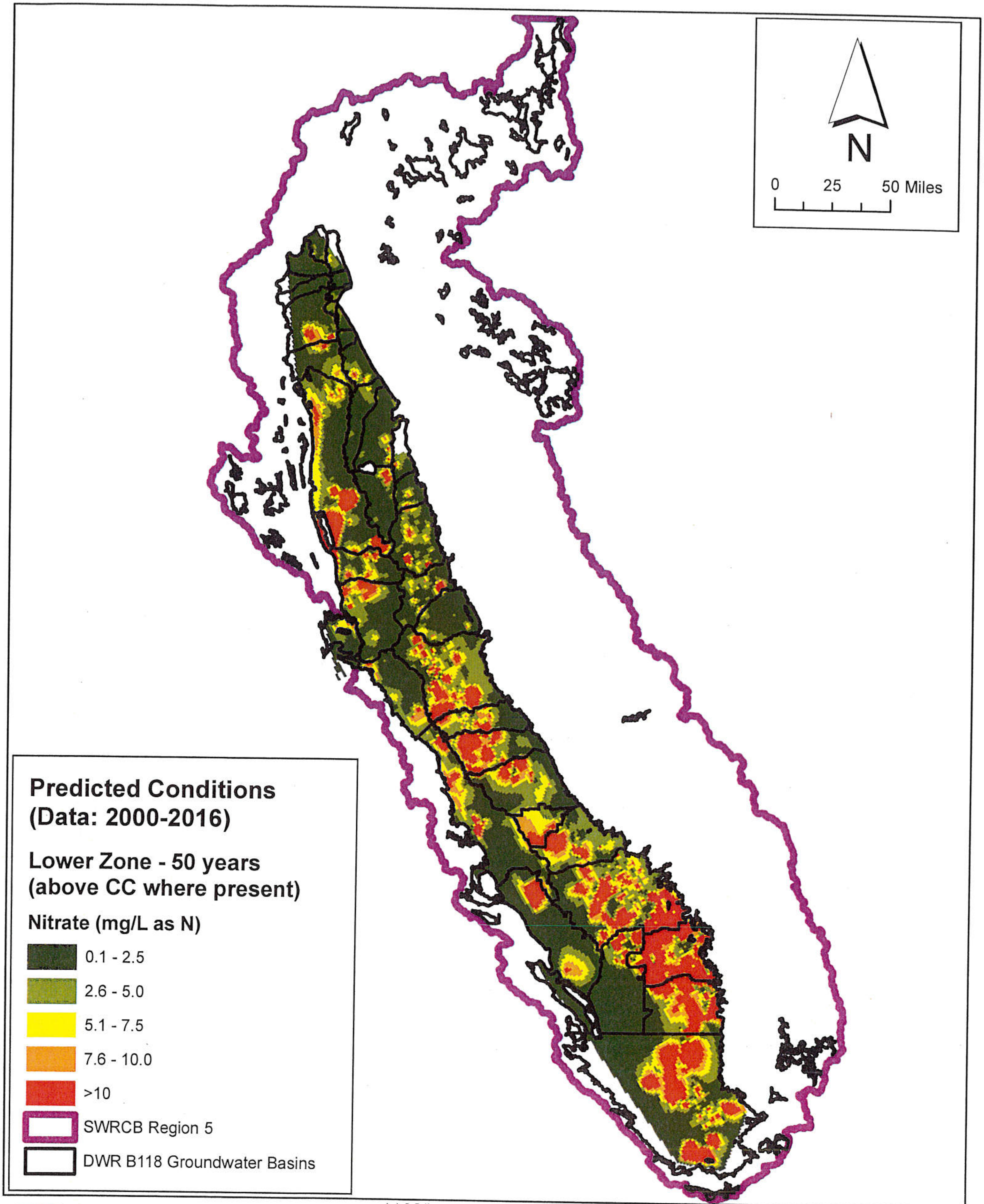

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Figure 109